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CRYSTALLOGRAPHY
FOR
BEGINNERS,
WITH AN
APPENDIX ON THE USE OF
THE BLOWPIPE
AND THE
DETERMINATION OF COMMON MINERALS

(After the method of Dr. Albin Weisbach).

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LONDON :
SIMPKIN, MARSHALL, HAMILTON, KENT & CO

1896.

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TO THE
PAST AND PRESENT STUDENTS IN
MINERALOGY

AT THE
BIRMINGHAM AND MIDLAND INSTITUTE
AND
MUNICIPAL TECHNICAL SCHOOL, BIRMINGHAM,

IN WHOSE COMPANIONSHIP HAVE PASSED
SOME OF THE PLEASANTEST HOURS OF HIS TEACHING,
AND BY WHOSE ENTHUSIASM
IN A SUBJECT TOO RARELY STUDIED
HE HAS BEEN STIMULATED IN HIS WORK,
THIS BOOK IS DEDICATED

BY THE
AUTHOR.

P R E F A C E .

CRYSTALLOGRAPHY has received but little attention in this country outside the universities and higher colleges, and at the present time, when utilitarian education is uppermost in the mind of the nation, it may seem inopportune to add to the few manuals hitherto published as an introduction to this subject, which by many is regarded as one of the components of "useless knowledge." The author believes, however, that crystallography, with its allied science, mineralogy, has many features to recommend it, whether we view its study as an education of the mind that delights in ascertaining the simple laws governing natural phenomena, or whether we view it as a subject a knowledge of which may bring material benefit to those engaged in industry. Surely to have some acquaintance with crystallography, especially the physical side of the science, must be valuable to the manufacturing and analytical chemist, the geological surveyor, and the prospector ; while it is evident that it must be an advantage to the stone merchant, the gem setter, and the jeweller, to supplement their traditional practical knowledge by the precise distinctions among precious stones pointed out by the crystallographer.

That the subject is not a popular one the author considers is due to the fact that no attempt has been made to make it popular. Thirty or forty years ago those who had any acquaintance with chemistry or electricity were comparatively few ; but these subjects have been made popular, and at the present time thousands are studying these sciences when formerly there were but tens.

Many have attempted to obtain an insight into crystallography, but, though earnest, have failed for two reasons : First, they have found the subject treated mathematically without any attempt to bring the explanations below the high level of the mathematical mind. Second, illustrative specimens are expensive, and models have not been supplied with the text in order to clench an argument in reference to crystallographic laws. These defects the author has tried to remedy : firstly, by the rather slow but sure process of progressive exercises and examples to follow up all explanations involving mathematical principles : and, secondly, by supplying sheets of models, which, when put together, will help the student over many difficulties. Further, a small cheap set of illustrative specimens is published to accompany the book, so that crystalline form, cleavage, optical, and other properties of crystals may be practically studied.

There is in this book no intention to treat mineralogy as a whole, but the abstract of Professor Dr. Albin Weisbach's tables (permission to introduce which has been given by their distinguished author) will be found valuable in classes in mineralogy where the practical method of Professor Groth referred to in the body of the work can be adopted, and, further, the blowpipe course recommended for the examination of minerals the author knows from experience to be a reliable one.

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Birmingham, May, 1896.*

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CRYSTALLOGRAPHY

FOR

BEGINNERS.

PRELIMINARY CHAPTER.

Instructions for Preparing the Models.

As the models, &c., of Plates III. and IV. will be continually wanted while studying with this book, it would be well to prepare them at once, according to the following directions :—

Saturate each plate with freshly-prepared paste, brushed in at the back ; give sufficient time for the paste to be thoroughly absorbed. Then lay the plate with its pasted side on to a piece of thin cardboard—three-sheet Bristol board is a convenient thickness—press out all folds with a soft rag, working from the centre outwards, and dry between paper laid on a flat table, covering the folds of paper on the upper side with a weighted drawing board. Lift off the paper occasionally to see that no mishap arises from paste which may accidentally have got on the front side of the plate. When thoroughly dry and stiff the models are ready for cutting out. Lay the sheet on a piece of glass, and cut the models out by means of a sharp penknife, or, what is better, a shoemaker's knife, kept sharp by rubbing on a stone, or on a piece of fine emery cloth glued on to a strip of wood, after the fashion of a razor strop. Another

2 INSTRUCTIONS FOR PREPARING THE MODELS.

method is to cut out the models with a sharp chisel. The sheet is put on a board, the chisel pressed firmly on the line of the figure, and a slight blow given with a mallet. The chisel makes a clean, sharp cut, and there is the advantage that the chisel may be inclined so as to cut a bevelled edge, and this bevelled edge, as may easily be seen, enables one to make neater joints than a square edge would. After a model has been cut out, the lines inside the figure are run over with the knife until the card-board is cut through to about half its thickness at all lines inside the model, and all is then ready for gluing up.

For connecting the edges of the net which has been cut out various plans have been adopted. Mr. Jordan, in his set of nets, "Elementary Crystallography," published by Thomas Murby, leaves tags or overlapping pieces. These tags are coated with thick gum, which is allowed to dry, and then in order to glue up the net the tags are wetted, and the parts united. Others leave the nets without tags, as in this book, and use strong thick glue, which is put on the edges with a camel's hair brush. The model is then folded up into form, and held until the glue is dry.

The following method I have found the quickest and best:—Obtain from a stationer a sixpenny tube of so-called "Seccotine" (Messrs. M'Caw, Stevenson, & Orr, Linenhall Works, Belfast, are makers). Having prepared two or three of the nets for gluing, unscrew the cap of the tube, run the smallest quantity of seccotine along an edge, press together for a minute or two, and put aside. Now take up a second model, do an edge of this in like manner, and so on with the others you have prepared. By this time the joint of the first net will be thoroughly set, and a second joint may be made without risk of undoing the first, and this process can be repeated until all the models you have prepared are complete.

One of the students in my mineralogy class (Mr. Wastell) has made many experiments in joining up the nets, and

has produced extremely neat models by cutting out completely the different faces of the drawings after they have been pasted on cardboard, then bevelling each piece thus cut out. The bevelled pieces are gummed on to thin tough paper in proper order, with a few tags or flaps left on the outside edges. These tags are gummed, and the net is folded up and bound round with cotton to secure the edges until the gum is dry. The models may be painted with Aspinall's enamel, or simply sized and varnished.

Although the results obtained by the above method are exceedingly pleasing, I have not recommended it, as only an enthusiast would give the necessary time and trouble. Moreover, this method would involve the re-lettering of the faces of the models by hand if they are to be used in the way described in the book.

The goniometer, Plate III., figures *C* and *M*, may with advantage be pasted on stiffer cardboard than the nets.

Before fitting this up look at figure IV., page 7, in order to obtain a general idea of the instrument when complete.

After cutting out the semi-circles *C* and *M* take a small cork, about the diameter of the incomplete circle at *M*, in centre of the graduated semi-circle, and cut away about two-thirds of the cork by a longitudinal cut; see figure *a*.



Fig. *a*.

Now, by means of glue or seccotine, fasten the face *t* of this cork on to the *back* of the graduated semi-circle, so as to occupy about the position of the incomplete circle *M*, taking care to keep the edge *c* parallel to the straight edge of the semi-circle, but well within it. Run a pin through the centre of the semi-circle *C* from the front, and now, pressing the semi-circle *C* well up to the head of the pin, run the point through the centre of the graduated semi-circle *M* into the cork, and press the pin home, when you have the goniometer complete, unless perhaps the point of the pin should protrude

4 INSTRUCTIONS FOR PREPARING THE MODELS.

through the cork, in which case it will be necessary to cut the point off, or file it down. This trouble can of course be prevented by choosing a pin of suitable length to begin with.

The drawing of axes Plate IV., figure 9, should be cut out along the lines forming the square border. Run a pin through the intersection M , and through the points A, A', B, B', C, C' , also through the dots marked at $\frac{1}{3}a, \frac{1}{2}a, \frac{2}{3}a$, and through similar dots on the other axes. After the holes have thus been made, the burr on the back of the cardboard should be scraped off with a knife, or cleaned off with a piece of flattened pumicestone.

LESSON I.

General Notions. Constancy of Angles.

BEFORE attempting to define a crystal or crystalline substance the student should see a few crystals, and become acquainted with their general properties.

Purchase from a chemist or druggist a few ounces of each of the following salts:—(a) blue vitriol, (b) washing soda, (c) Rochelle salt, (d) Chili saltpetre (nitrate of soda), (e) sulphate of nickel, (f) alum.

It is well to ask the shopkeeper to let you look over his stock, as you may be able to pick out from a large quantity of the salt some well-formed crystals. These should be saved, but with the general mass of each salt you may proceed to obtain crystals by the following method.

Experiment.—Put into a pipkin, or an earthenware basin, about half a pint of water, and add two to three ounces of the blue vitriol, and heat to near boiling. When a pipkin is used this may be done directly over the fire, but with a basin it is well to place the basin in a saucepan of water, after the fashion of a water bath. When dissolved, pour the blue solution into a shallow vessel, such as a saucer, soup plate, or photographic dish, according to the quantity made, and let the solution cool as slowly as possible. Perhaps the most convenient way to do this is to put the vessel in the oven, or on the hob, at night, and remove it before the fire is lighted the next morning. When thoroughly cold, or probably before, you will find crystals of blue vitriol formed at the bottom of the saucer. Pour off the mother liquor from the crystals into a saucer, and set this aside in a cool place, when, after a time, a further crop of crystals will be obtained. Now pick out from the mass of crystals one or two of the best you can find, and reserve them for study.

Repeat with the other salts the experiments described as above, when you will obtain, in some cases, at any rate (blue vitriol, Rochelle salt, and alum probably giving best results), several specimens of crystals.

The crystals of minerals found in nature have been formed in various ways, some by cooling from a molten mass, as with crystals found in solidified lava, some by separation from solution, as with calcite and quartz, others by slow reduction of metallic solutions; in all cases it being requisite that the ultimate particles or molecules of the crystal have, as it were, been in a state of freedom. On losing this freedom the molecules unite together, not haphazard, but according to certain laws, which impress upon the solid produced the characteristics it is the function of the crystallographer to discover.

These natural crystals are, generally speaking, finer and more suitable for study than those prepared in the way described; and that the student may have no difficulty in obtaining typical specimens, I have arranged for the publication of a cheap set to accompany these lessons, particulars of which will be found at the end of the book. With the specimens he has obtained himself, or with those in the set just referred to, the student should proceed to verify the following points.

(i.) **Constancy of Angles.**—Look carefully at a few crystals of one of the salts, blue vitriol for example; you will note that each crystal consists of a number of planes, or *faces*, more or less bright, meeting each other so as to produce geometrical forms (the line in which two of the faces meet is called an *edge*), and though at first sight the various crystals of blue vitriol look different, you will soon see that though the faces may vary very much in size, yet if you put two of the crystals side by side, you can even by inspection see that the angles made



Fig. 1.

illustrate this point, which is one of fundamental importance,

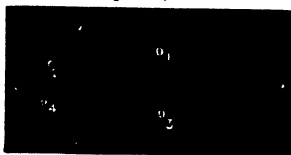


Fig. 2.

in figures 1, 2, 3, forms you will not unlikely find among the crop of alum crystals. The form, figure 1, is called the regular octahedron.

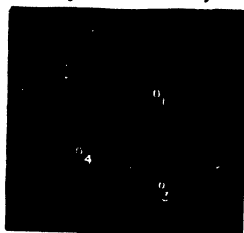


Fig. 3.

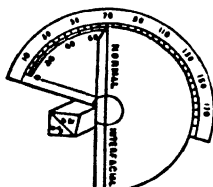


Fig. 4.

by corresponding planes in the two crystals are the same. Compare now two crystals of alum, or of Rochelle salt, and the same peculiarity will be observed. Probably among the crystals you have obtained the alum crystals will best illustrate the important law of constancy of angles. The better to

put together the three crystal nets D, E, F, of Plate III., according to the instructions already given, and you will have models of the three solids represented

In order to measure angles, a *goniometer* is required. A cardboard goniometer, sufficient for present purposes, may be made expeditiously by following the directions already given. To use the instrument when made, place the model of the

crystal between the jaws of the goniometer, as shown in figure 4, when the angle is indicated by position of the arrow. Thus in figure the angle indicated is 70° about; this means that the angle *between normals* is approximately 70° .

Normal Angles and Interfacial Angles.—When two planes are inclined to each other, the inclination may be measured in two ways. Thus, if OA , OB , figure 5,

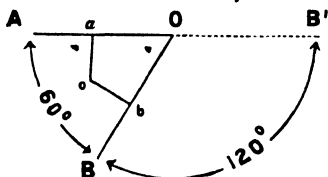


Fig. 5.

are traces of two planes at right angles to the paper, the angle between the planes may be measured by considering that there is no angle, or

that the angle is 0° between the lines when OB coincides with OA , but as OB revolves in the opposite direction to the hands of a clock, or *counter clockwise*, about the point O , the angle increases, and the extent of the movement measures the angle. An angle between two planes measured in this way is termed an *interfacial* angle. Or, we may proceed in another way. Suppose we consider that there is no angle, or that the angle is 0° , when OB coincides in direction with OA , but does not fall upon it as indicated by the dotted line OB' , and that as OB' is revolved about the point O in a clockwise direction, the angle increases. This mode of measuring is adopted usually in crystallography, and the angles thus obtained are called *normal angles*, or angles between normals, since they coincide with the angles between perpendiculars (normals). In figure 5, for example, the interfacial angle AOB is 60° , while the normal angle $B'O B$ is 120° . Now, aO , bO are perpendiculars or normals to the lines AO , OB representing the faces, and the angle aOb , the angle between these normals, is equal to the angle $B'O B$, as is obvious from the consideration that $B'O B$ is $180^\circ - AOB$. Also since in the figure $OaOb$ the interior angles make up 360° , and the angles OaO and OOb are together $= 180^\circ$, it follows that the angle aOb is also $180^\circ - AOB$.

When the student comes to the lesson on Spherical Projection he will see how useful is this method of measuring angles. In some books measurements are given in interfacial angles, but the much more convenient method of normal angles is rapidly becoming general.

In using the cardboard goniometer, see that the plane of the instrument is at right angles to the edge formed by the two planes, the angle between which is being measured, and further see that the jaws of the instrument are pressed well on to the planes. With such a rough instrument it is not likely that measurements of much service can be obtained—all that is intended is that by its means the student shall understand the meaning of “constancy of angles” It will be well in using the instrument to measure first the normal angle between two faces of a model, and then the interfacial angle of the same two faces. These together should, of course, make up 180° . Further, if the instrument is properly made, the sum of the normal angles, measured from face to face, in going round a *zone** of a good model, should make up 360° .

To verify the law of constancy of angles in the models D, E, F, take first the model D, and you will find approximately that you will obtain the following measurements :

Between $o_1 o_2$ about 70° .

„ $o_1 o_3$ „ 109° .

Further, you will find that the angles $o_2 o_3, o_3 o_4, o_4 o_1, o_1 o_2$, &c., = $o_1 o_2 = 70^\circ$ about, while $o_2 o_4, o_1 o_3, o_2 o_3$, &c., = $o_1 o_3 = 109^\circ$ about. Now try the models E and F, and you will obtain, in spite of the marked difference in appearance of the models, precisely the same angles between corresponding faces. Thus, between $o_1 o_2$ of models E and F the angle is 70° about. It may be stated here that measurements of crystals to which the models correspond

* For explanation of this term see next page.

give $o_1 o_2 = 70^\circ 32'$, and $o_1 o_3 = 109^\circ 27'$. Each of these models so different in appearance would be called by crystallographers a regular octahedron.

Zones.—To understand the meaning of the very important term *zone*, the student should have at hand the mineral specimens supplied with the book, and also the cardboard models made from the nets of Plates III. and IV.

Take first the crystal of gypsum, and also the model of it (Plate III. L). Note an edge such as that formed by the faces m_1, b . Place this edge horizontal, and turn the crystal or the model round this edge as a horizontal axis, when it will be noticed that several edges come successively into the horizontal position, showing that these edges are parallel to each other. Now three or more faces which give parallel edges constitute a zone. Thus, with gypsum, the six faces $m_1, b, m_2, \bar{m}_1, \bar{b}_1, \bar{m}_2$ constitute a zone. With model, Plate III. D (octahedron), the faces $o_1, o_2, \bar{o}_1, \bar{o}_2$ constitute a zone, while the faces o_1, o_2, o_3 are not in one and the same zone. Two or more faces are said to be *tautozonal* or *heterozonal*, with a third, according as they lie in the same or different zones. Thus, $o_1, o_2, \bar{o}_1$ are tautozonal planes; o_1, o_2, o_3 are heterozonal planes.

Poles.—The faces of crystals are often referred to as poles. Thus we may speak of the angle between the faces o_1, o_2 of the model D, or we may speak of the angle between the poles $o_1 o_2$ of the same model. When poles are spoken of we more clearly appreciate that the angle between normals is meant. This matter will be referred to again when on the subject of Spherical Projection.

EXERCISES.

11. Determine with the cardboard goniometer the angles (normal) between the following pairs of faces. Give also the interfacial angles.

In model B, Plate III. In model 5, Plate IV. On crystal of gypsum.

Between e_1 e_3

" e_1 $\bar{e}_7$

Between m_1 m_2

" m_2 $\bar{m}_1$

" $\bar{m}_1$ $\bar{m}_2$

" $\bar{m}_2$ m_1

Between b m_1

" m_1 $\bar{m}_1$

" $\bar{m}_2$ b

12. In model 6, Plate IV., give the names (m_1 , m_2 , &c.) of the poles or faces forming the different zones on the model.

13. How many edges are there in model D, Plate III.? How many in model E of Plate III.? and how many in model F of Plate III.?

14. You will have noted from the last exercise the number of edges in the same crystalline form may be different in some instances. What should you judge to be the maximum and what the minimum number of edges in the octahedron and in the cube?

15. In model, Plate III. A (four-faced cube), name the faces which constitute one or two of the zones on the model. Name a face with which e_1 and e_2 are tautozonal. Name also a face with which these faces are heterozonal.

LESSON II.

Symmetry.—The Six Systems.

Planes of Symmetry.—In common language a body is said to be symmetrical when, if we draw an imaginary plane through the body, we find the two parts similar and similarly placed in reference to the plane. Thus, if we imagine a vertical plane passing through the nose and back-bone of an upright man, we have similar parts on opposite sides; so a man may be said to have *one* plane of symmetry, for no other plane will divide a man into two similar parts.

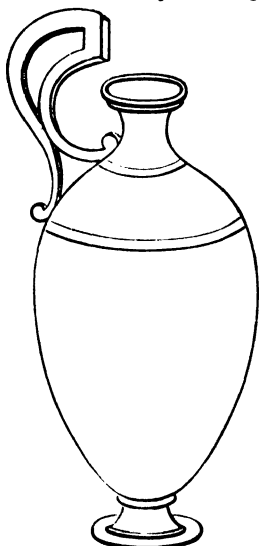


Fig. 6.

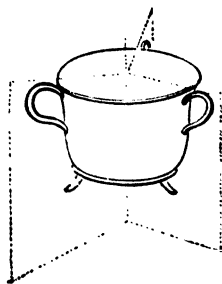


Fig. 7.

Similarly the Greek jug of figure 6 has one plane of symmetry, viz., that through and in the plane of the handle; while the three-handled cup of figure 7 has three planes of symmetry at an angle of 120° to each other. We may then recognise a plane of symmetry in a figure by cutting the figure in two through a supposed plane of symmetry; then, laying one of the severed halves upon a mirror, see if the figure is now apparently complete when the reflected portion is viewed in

conjunction with the applied portion.

Distinction between Geometrical Symmetry and Crystallographic Symmetry.—

When we consider crystalline forms, we have, however, not merely to look at the general or geometrical appearance of the figure, and the particular angles on opposite sides of the plane of symmetry, but we must learn to recognise faces themselves, and see whether the faces which appear on one side of the plane of

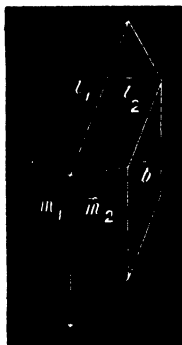


Fig. 8.

symmetry appear also on the other side. Take the crystal of gypsum from the box, and also the model you have made from the net, Plate II. L, and look down on the face b (see also figure 8). Notice that this face b is distinctly brighter than the faces $l_1, l_2, \bar{l}_1, \bar{l}_2$, and when held in a good light has not quite the same appearance as the faces $m_1, \bar{m}_2, \bar{m}_1, \bar{m}_2$. Now turn the crystal so as to look down upon the edges forming the junction of the planes m_1, m_2 , and l_1, l_2 , and you will see at once that if the crystal were cut through by a plane passing through these edges, this plane will be a plane of symmetry, for the bright plane b appears on the opposite side as $\bar{b}$, the rough faces l_1, l_2 appear on the opposite side of the plane as the planes $\bar{l}_1, \bar{l}_2$, and similarly the faces m_1, m_2 appear on the opposite side of the plane as $\bar{m}_1, \bar{m}_2$. In fact, as you may easily perceive, if the crystal were cut with a knife through a plane, passing through the two edges referred to above, we should have two halves, either of which being placed on a looking glass would give the appearance of the complete crystal. If you care to sacrifice your crystal, you can easily separate it, and make the experiment.

Now take up a crystal of blue vitriol (copper sulphate), and also the model H, Plate III., you have made, and look them carefully over. The faces of the blue

vitriol are generally very much alike, but you may possibly recognise some differences. One of the faces is perhaps *striated*; if so, you will find the face parallel to it also striated, but you will look in vain for a plane of symmetry, that is, any plane through which the crystal might be divided into two symmetrical halves, as with gypsum. Copper sulphate then has no plane of symmetry, while gypsum has one.

Next take from the box the crystal of barytes, and the two models made from the nets of Plate IV., figures 7 and 8. Try with the help of the models to find the planes. If the crystal supplied in the box corresponds to figure 8 of Plate IV., you will recognise the two bright triangular planes giving the chisel-like appearance to the crystal, as the planes $m_1, \bar{m}_2$ of the model, while the dull prism planes are those indicated in the model by the letters u_1, u_2 . Or if the crystal supplied in the box should correspond somewhat to figure 7 of Plate IV., you will notice that the two opposite faces which show a pearly or iridescent appearance correspond to those marked c and $\bar{c}$ in the model, while the bevel faces which give the chisel-ended appearance to the crystal are the faces w and l , the remaining faces on the model, o_1, o_2 , &c., being the remaining well-marked faces.

In comparing the crystals with the models, remember that it is seldom we have the regularity in the development of the faces that we represent in the models, but the crystals supplied in the boxes have been selected as far as possible so that the models shall fairly represent them.

Having made these observations, with barytes it will easily be seen, more especially with the model 7 of Plate IV., that there are three planes of symmetry in barytes crystals, viz.:—One plane A (figure 9) at right angles to the plane c , and parallel to the edge made by the planes c, o_1 ; one plane B at right angles to the plane c and the imaginary plane A, and parallel also to the edge formed by

c and w_1 ; one plane C parallel to c , and passing through the edge formed by o_1, o_2 . These three planes being at right angles to each other.

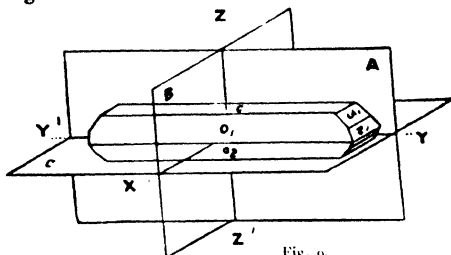


Fig. 9.

Next take up the cleaved specimen of calcite from the box, and also the model made from the net K of Plate III. Note that in this model there are three planes of symmetry, but not at right angles to each other as with barytes. The three planes being at 120° from each other, viz.:—One plane at right angles to the face r_1 , and passing through the edge formed by r_2, r_3 ; one plane at right angles to the face r_2 , and passing through the edge formed by r_1, r_3 ; one plane at right angles to the face r_3 , and passing through the edges formed by r_1, r_2 .

Now examine the nickel sulphate crystal, and the model made from the net N of Plate III., and you will find five planes of symmetry, viz.:—Four all at right angles to the

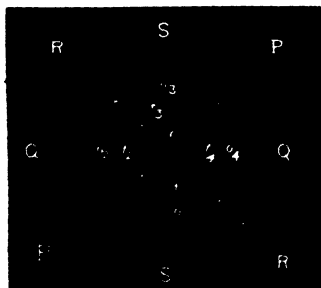


Fig. 10.

plane c , but at 45° to each other, two of the planes passing from corner to corner of the square plane c , and the other two being parallel to the edges of the plane c (see figure 10); and one plane parallel to the plane c .

Lastly take up the cube of fluor spar, and the model of

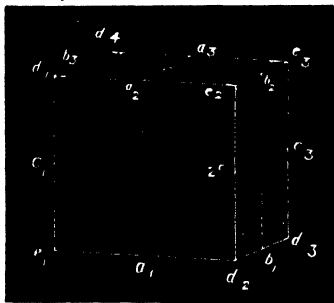


Fig. 11.

the cube made from the net G of Plate III., and see that there are nine planes of symmetry, viz.:—Three parallel respectively to the planes a , b , c , the traces of which are represented in figure 11 by the dotted lines $a_1 a_2 a_3$, $b_1 b_2 b_3$, $c_1 c_2 c_3$; two at

right angles to the face a , and at right angles to each other, passing from corner to corner of the face, traces indicated by $e_2 d_3$, $d_2 e_3$ of figure 11; two at right angles to the face b , and at right angles to each other, passing from corner to corner of the face, traces indicated by $d_1 d_2$, $e_1 e_2$ of figure 11; two at right angles to the face c , and at right angles to each other, passing from corner to corner of the face, traces indicated by $e_2 d_4$, $d_1 e_3$ of figure 11.

Now all of what are known as *holohedral* crystals which have been examined can be classed into one or other of six systems given in the table on page 17, and of which the six specimens referred to in this lesson are types.

Examine the cube of fluor spar in the box of specimens; the faces are identical in appearance, but it is quite possible to have a cubic crystal of a mineral, apophyllite for example, in which two of the opposite faces are pearly, while the remaining four faces are bright.

Again, with a cubic mineral, cuprite for example, while we may often meet with cubes, yet the form is often a parallelepiped, or square prism; and in some cases, as in the variety of cuprite, called chalcotrichite, the prisms are so long in relation to their area as to be called acicular; still in all cases there are nine planes of symmetry, however varied the dimensions of rectangular figure may be.

SIX SYSTEMS OF CRYSTALS.

SYSTEM.	SYMMETRY.	EXAMPLES.
I. Anorthic.	No plane of symmetry.	Blue vitriol, or Copper sulphate Axinite
II. Mono-symmetric.	One plane of symmetry.	Gypsum Washing soda
III. Ortho-rhombic.	Three planes of symmetry at right angles to each other.	Barytes Rochelle salt
IV. Hexagonal.	Three planes of symmetry at 120° from each other, or seven planes of symmetry, six at 30° , and one at right angles to all the others.	Calcite Nitrate of soda Apatite Beryl
V. Tetragonal.	Five planes of symmetry, four at 45° to each other in succession, one at right angles to all these.	Nickel sulphate Idocrase
VI. Cubic.	Nine planes of symmetry.	Iron pyrites Fluor spar Alum

Various names have been given to the six systems by different authors. The above are those adopted by Maskelyne, *Morphology of Crystals*, 1895, p. 4. It may be useful here to give some of the equivalent names as adopted by writers on crystallography. In the following table names in the same column are equivalents :—

I.	II.	III.
Anorthic	Mono-symmetric	Ortho-rhombic
Doubly oblique	Oblique	Prismatic
Triclinic	Monoclinic	Trimetric
Asymmetric	Clino-rhombic	Rhombic
One and one membered	Hemiorthotype	Orthotype
	Two and one membered	One and one axial
<i>Eingliedrig</i>	<i>Zwei und eingliedrig</i>	<i>Zweigliedrig</i>
IV.	V.	VI.
Hexagonal	Tetragonal	Cubic
Rhombohedral	Quadratic	Regular
Three and one axial	Pyramidal	Isometric
<i>Sechsgliedrig</i>	Two and one axial	Tesseral
	<i>Viergliedrig</i>	Octahedral

In numbering the systems I have followed Miller, commencing with the system of no symmetry. Many authors reverse this order, commencing with the system of highest symmetry.

EXERCISES.

21. How many planes of symmetry are there in each of the following plane figures, the lines bounding the figures being regarded as identical?

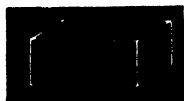
- (i.) A square. (ii.) An equilateral triangle.
 (iii.) A rhombus (fig. *a*). (iv.) A rhomboid (fig. *b*).

Fig. *a*.Fig. *b*.

- (v.) An isosceles triangle. (vi.) A circle.

22. How many planes of symmetry are there in each of the following solid figures, supposing all the faces to be identical in character?

- (i.) A parallelopiped or brick-shaped figure (fig. *c*).

Fig. *c*.

- (ii.) A square prism (fig. *d*).

Fig. *d*.

- (iii.) A cube. (iv.) A sphere. (v.) An octahedron.

23. If the parallelopiped of question 2 has the ends painted red, while the remaining four sides are green, how many planes of symmetry are there? If, while the ends are red, two of the parallel sides are green, and the remaining two white, then how many planes of symmetry are there?

Note. — The model of the cube, Plate III. G, and that of the prism of the ortho-rhombic system, Plate IV. 12, illustrate this point. In the cube there are nine planes of symmetry; in the prism, since each pair of faces is different in character, there are but three planes of symmetry.

24. Look over all the cardboard models you have made, and see how many planes of symmetry you can find in each.

LESSON III.

Crystallographic Notation. The Millerian System.

Weiss's System. Rationality of Indices.

FROM the experience the student has now had he will readily see that a crystal is a natural solid, contained by planes making various angles with each other, but these angles are constant in the same crystalline form, no matter to what extent the size of the planes may vary.

We will now learn by what other laws the inclination of the planes of a crystal are governed, but in order to understand these laws, we must first know in what manner the position of a plane can be expressed.

Draw (see figure 12) a perspective view of three lines, $XO\bar{X}$, $YO\bar{Y}$, $ZO\bar{Z}$, intersecting at O , and making

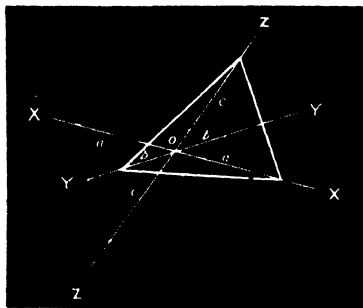


Fig. 12.

any angles with each other, and mark off on either side of O the equal lengths a and $\bar{a}$ on $XO\bar{X}$, the equal lengths b and $\bar{b}$ on $YO\bar{Y}$, and the equal lengths c and $\bar{c}$ on $ZO\bar{Z}$. The lengths a, b, c are

while the direction lines $XO\bar{X}$, $YO\bar{Y}$, $ZO\bar{Z}$ are called *axes*. The intersection at O is called the *origin*. Suppose a plane to lie in such a position that while one point in the plane is at the extremity of a , another point in the plane is at the extremity of b , while a third point is at the extremity of c , such a plane is called the *parametral plane*, or the 1 1 1

plane, and it is obvious that the lie of such a plane is known when we have the directions of the axes X, Y, Z given, and also the relative lengths indicated by a, b, c . Three lines in such a plane are represented in figure 12 by thick lines.

Hence, when the 1 1 1 plane is spoken of, the student can easily picture to himself the lie of the plane, supposing, as has already been said, the inclinations of the axes and the relative lengths of the parameters are given.

Suppose a plane to lie in such a position that it cuts the parameter a at one-half its length, the parameter b at one-third of its length, and the parameter c at one-fourth of its length. Then the lie of this plane would be known, and we could speak of it as the

$\frac{1}{2}$ of a , $\frac{1}{3}$ of b , $\frac{1}{4}$ of c plane.

This notation, however, is cumbersome, and it is spoken of as the

$\frac{2}{3} \frac{4}{5}$ plane,

which conveys the idea of a plane cutting the parameters in the way indicated; similarly the symbol $\frac{2}{3} \frac{3}{5}$ would indicate a plane which cuts off one-half of a , one-third of b , and one-fifth of c .

It will be easier at first, perhaps, to represent the axes as they are in many systems of crystals, viz., at right angles to each other, and to take the parameters a, b, c all equal.

In Plate I., figure 2, pqr is a representation of the plane 1 2 3, which, as will be noticed, cuts the parameter a at its extremity, the parameter b at one half its length, and the parameter c at one-third of its length.

It should be pointed out here that all parallel planes in the same octant, such, for example, as the positive octant (that bounded by the planes ZOX, ZOY, YOX) have the same indices. Thus a plane 2 2 2 means a plane passing through the points $\frac{1}{2}a, \frac{1}{2}b, \frac{1}{2}c$, and this is obviously parallel to the plane 1 1 1. Similarly the plane $20 \frac{3}{5} 0 = \frac{1}{5}a, \frac{3}{5}b, \frac{1}{5}c$ is parallel to the plane 2 3 5, and is

considered identical with it. In fact, any three numbers which have the same ratios express the same plane, and it is usual always to bring these ratios to the simplest form.

Example. The plane 12 24 36 is the same as the planes 6 12 18, 24 48 72, 3 4 6, or 1 2 3. Thus, having given three indices, we may multiply or divide them *all* by any number we please, and the same plane is still expressed by the new ratios obtained

Suppose a plane to pass through the extremity of c , but to cut off a very small but equal fraction of a and b , one-thousandth of each for example, then the indices of the plane would be 1000 1000 1, or, dividing each index by 1000, the plane is expressed as 1 1 $\frac{1}{1000}$. Now, the smaller the fraction of a and b taken, the steeper and steeper the plane becomes, and the smaller and smaller is the last index, until, when the plane is parallel to c , the last index is $\frac{1}{\infty}$, or 0, so the plane is written 1 1 0. By the same reasoning, it will be seen that a plane parallel to the axis X will have its first index 0, and a plane parallel to the axis Y will have its second index 0. If the plane is parallel to two axes, to Y and Z for example, then its indices are 1 0 0.

In figure 2, Plate I., the plane tw represents the 1 0 0 plane.

Negative Indices.—So far we have learned only to represent planes in what is called the positive octant. But let us take planes in one of the other octants. Say a plane which cuts $O\bar{X}$, $O\bar{Y}$, and $O\bar{Z}$. The parameters measured from the origin O in the direction OX , OY , OZ are considered positive, while in the direction $O\bar{X}$, $O\bar{Y}$, $O\bar{Z}$ they are considered negative, hence the plane which cuts the extremities of these negative parameters will be

$$\frac{1}{2} \text{ of } \bar{a}, \frac{1}{2} \text{ of } \bar{b}, \frac{1}{2} \text{ of } \bar{c},$$

and this statement is expressed as $\bar{1} \bar{1} \bar{1}$, the negative signs

over the indices implying that the parameters have been taken in the negative direction.

The plane represented by thin lines in figure 12 is $\frac{1}{2}$ of $\bar{a}$, $\frac{1}{3}$ of $\bar{b}$, $\frac{1}{6}$ of $\bar{c}$, and its indices are $\bar{1} \bar{1} \bar{1}$.

On considering this subject, in connection with the exercises at end of the lesson, the student will note that when we have established the indices for one plane, the plane parallel to it has the same indices, but reversed in sign, thus—

Plane.	Plane parallel, but on opposite side of origin.
$1 \ 1 \ 1$	$\bar{1} \ \bar{1} \ \bar{1}$
$1 \ 2 \ 3$	$\bar{1} \ \bar{2} \ \bar{3}$
$1 \ \bar{2} \ 3$	$\bar{1} \ 2 \ \bar{3}$
$1 \ 0 \ 0$	$\bar{1} \ 0 \ 0$
$h \ k \ l$	$\bar{h} \ \bar{k} \ \bar{l}$
$h \ \bar{k} \ \bar{l}$	$\bar{h} \ k \ l$
$h \ k \ 0$	$\bar{h} \ \bar{k} \ 0$

The symbols $h \ k \ l$ used in this last illustration are general symbols, just as in algebra, and may express any three different *rational* numbers. We shall find that using these symbols often saves time and space in expressing certain laws.

Haüy's Law of Rationality of Indices.—It might well be supposed that the angles between the planes of crystals could have *any* indices, that is, that the planes could have *any* inclination, but a very remarkable law was discovered by Haüy in reference to this point. In the first place, the indices of planes are generally simple, such as $1 \ 2 \ 3$, $1 \ 2 \ 0$, $1 \ 1 \ 5 \ 3$, &c.; but this is not all. Haüy established a law that *the indices of a plane must be expressed by rational numbers*. Thus, while such indices as $1 \ 2 \ 3$, $5 \ 7 \ 9$ are usual, there is no reason why a plane should not be $21 \ 57 \ 100$ for example,

but a plane cannot have the indices $1 \sqrt{2} 0, \sqrt{3} 4 6$, &c., that is, no index must be a surd, as the mathematician calls it.

Notation of Weiss.—Though Miller's system of notation of planes just explained is admittedly the best, and is rapidly superseding all other systems, it may be well to refer to the method of Weiss, and later on to the system of Naumann, as these notations, more especially that of Naumann, are met with even now in many works.

In the Millerian system, as we have learned, fractions of the parameters are taken, and the denominators of these fractions form the indices. In Weiss's system *multiples* of the parameters are used as indices, and one of these indices is taken as unity. Thus, if the parameter b is unity, we have the symbol $2a \ b \ 3c$ for a plane which cuts the Y axis at the extremity of the parameter b , the X axis at twice the length of the parameter a , and the Z axis at three times the parameter c . To bring this into the Millerian notation, we must divide each index by such a number that we can have fractions of $a \ b \ c$ each with a numerator = 1. Thus, with the plane just mentioned,

$$2a \ b \ 3c = \frac{2}{3}a \ \frac{1}{3}b \ \frac{3}{3}c = \frac{1}{3}a \ \frac{1}{3}b \ \frac{1}{1}c.$$

Hence the plane in Miller's notation would be $3 \ 6 \ 2$.

Again, suppose we have the Millerian symbol, $1 \ 2 \ 3$, and we wish to convert it into the system of Weiss, with, say, b as unity, then we note

$$1 \ 2 \ 3 = \frac{1}{1}a \ \frac{1}{2}b \ \frac{1}{3}c.$$

Multiply by the least common multiple, 6, and we have

$$= 6a \ 3b \ 2c.$$

Now divide by 3, and we have

$$2a \ b \ \frac{2}{3}c, \text{ the required symbol.}$$

In figure 13 is represented this particular plane in each

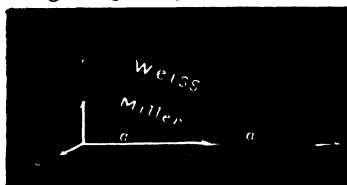


Fig. 13.

system, and it will be observed that the planes are parallel, and so, crystallographically, they are identical.

Take the symbol 1 2 0 of Miller, we have it in full as

$$\frac{1}{1}a \ \frac{1}{2}b \ \frac{1}{0}c = a \ \frac{1}{2}b \ \infty c = 2a \ b \ \infty c ;$$

so Weiss's symbol is $2a \ b \ \infty c$, and it is evident that the plane 1 0 0 of Miller will become $a \ \infty b \ \infty c$.

Before Naumann's system can be understood the meaning of the term *form* is required. This will be treated in the next lesson.

When with Millerian symbols the middle index is 0, it is impossible to make the middle index unity in Weiss's system. In such a case one of the other indices may, if thought well, be made unity. Thus, 3 0 5 in Miller means $\frac{1}{3}a \ \frac{1}{0}b \ \frac{1}{5}c$. Multiply by 15, and we have $5a \ \frac{15}{0}b \ 3c$, but $\frac{15}{0}b = \infty b$. Hence the plane in Weiss's notation must be written $5a \ \infty b \ 3c$, or, with a as unity, $a \ \infty b \ \frac{3}{5}c$.

EXERCISES.

31. Ascertain whether among the following planes any are repeated. In other words, are the ratios of the indices in the several planes all different? If not, point out two or more that have the same ratio.

a 1 1 1	e 1 0 4	k 2 0 8
b 2 3 4	f 3 5 6	l 3 7 10
c 5 5 5	g 6 9 12	m 15 25 30
d 4 6 8	h 1 0 8	n 6 14 20

32. The following planes, containing in many cases fractional indices, may be simplified so as to express the planes in the usual indices of whole numbers. Reduce all the symbols to the usual form.

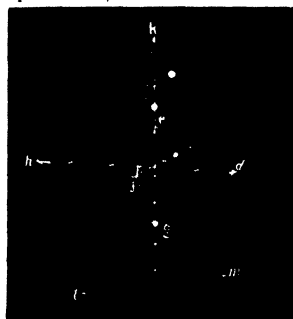
a 1 1 $\frac{1}{2}$	c 1 1 $\frac{1}{4}$	e 1 $\frac{3}{4}$ $\frac{3}{4}$
b $\frac{1}{2}$ $\frac{1}{2}$ 0	d 2 $\frac{3}{4}$ 4	f 0 $\frac{3}{4}$ 0

33. Write out in full the meaning of each of the following symbols as applied to planes, also make a free-hand sketch of axes and parameters, and represent each plane in your drawing, after the fashion of figure 11.

a 1 1 1	g 1 1 1	o 1 0 0
b 1 1 2	h 0 0 1	p 1 0 0
c 1 1 2	k 0 0 1	q 0 1 0
d 1 1 0	l 1 2 3	r 0 1 0
e 1 1 2	m 3 2 1	s 0 0 1
f 2 1 0	n 2 2 1	t 0 0 1

34. Find the indices for the planes $ie d$, $fg h$, $fk h$, $fd g$, lm , represented in the following figure.

NOTE.—The point d is intended to be at two-thirds of the parameter a measured from the origin, f is at one-half of the parameter b , h is at the extremity of the parameter $\bar{a}$, k is at the extremity of the parameter c , g is at one-half of the parameter $\bar{c}$, while e is at one-third of the parameter c .



35. Which of the following planes, according to Haüy's law, are possible, and which impossible planes?

α	15	17	30	ϵ	3	4	20	k	4	3	2
b	$\sqrt{2}$	1	1	f	$\sqrt{2}$	$\sqrt{2}$	$\sqrt{2}$	l	$\sqrt{100}$	$\sqrt{25}$	$\sqrt{4}$
c	1	2	$\sqrt{3}$	g	$\sqrt{25}$	2	2	m	5	3	7
d	1	$\sqrt{4}$	$\sqrt{9}$	h	$\sqrt{5}$	$\sqrt{5}$	0	n	$\sqrt{17}$	0	0

36. Convert the following Millerian symbols into those of Weiss, with b as unity where that is possible.

a	2	3	4	e	0	1	1	k	2	5	7
b	2	2	1	f	1	2	3	l	1	6	6
c	1	1	1	g	3	2	1	m	0	0	1
d	1	0	0	h	1	3	5	n	0	1	0

37. Convert the following symbols of Weiss into Millerian indices.

a	$2a$	b	c	d	$3a$	b	$4c$	g	a	b	c
b	a	b	$2c$	e	∞a	b	∞c	h	$2a$	b	$2c$
c	a	b	$3c$	f	∞a	∞b	c	k	$5a$	b	$7c$

LESSON IV.

On Drawing Crystal Forms.

As a valuable exercise in understanding crystallographic notation, and also as extremely interesting work, it is well that the student should learn how to draw the intersections of planes in perspective when the symbols of the planes are given.

Crystal forms may be drawn in ordinary perspective, in isometric perspective, or in plan and elevation.

Consider the appearance presented to the eye by a cube under different circumstances. In drawing an object we may conveniently consider that we are tracing the form of the object as it would appear projected on a piece of flat glass held vertically between the object and the eye.

When the eye is situated so that three sides of the cube can be seen, then if the eye is near the cube, the appearance presented is that of A, figure 1, Plate I., in which the verticals g, h, g' are parallel, but all other parallel lines of the cube are converging. This is a drawing of the cube in *ordinary perspective*.

If the cube while in a similar position is gradually reduced in size, the lines c, a, c' and b, f, b' gradually converge less and less as the cube gets smaller, until, when the cube is very small (theoretically infinitely small), there is no convergence, and all parallel lines in the cube itself appear parallel in the drawing. This appearance is represented at B, figure 1. Plate I., and is a drawing of the cube in *isometric* or *parallel perspective*.

When the eye is placed immediately opposite one of the vertical faces of the cube, we have an *elevation* as at C_1 of figure 1. Plate I., and when the eye is opposite a horizontal face we have a *plan* as at C_2 of the same figure.

It is usual in works on crystallography and mineralogy to represent crystal forms either in plan and elevation, or in isometric perspective. It will be well perhaps to describe first the method of drawing in isometric perspective.

To Draw Three Parameters of equal length at right angles to each other in Isometric Perspective.—The following construction, as given by the late Professor J. S. Dana, is a convenient one.

Draw two lines, CC' , HH' , at right angles to each other, and intersecting at M (figure 9, Plate IV.). Make $MH = MH'$. Divide HH' into three equal parts, and through the points H, H', N, N' thus determined, draw perpendiculars to HH' . On the left-hand vertical set off below H' a part $H'Q$ equal to $\frac{1}{3} H'M$, and from Q draw $QB B'$. The part BB' is the projection of the horizontal parameter b .

Draw BS parallel to MH' and connect SM . From the point T in which SM intersects BN draw TA parallel to MH . A line (AA') drawn from A through M , and extended to the left vertical, is the projection of the parameter a .

Lay off on the right vertical a part $HR = \frac{1}{3} MH$, and make $MC = MC' = MR$. Then CC' is the projection of the parameter c .

When the three parameters are equal it is not usual to indicate them by different letters, but we shall find it a convenience in description to regard the parameters a, b, c , whether equal or not, as situated in the positions obtained in the above construction.

The student may with advantage make the above projection of parameters on a piece of cardboard, and divide each parameter into two equal parts, and also into three equal parts, as shown in Plate IV., figure 9. Or he may paste the drawing of Plate IV., figure 9, on to a piece of cardboard, then prick holes at the extremities of the axes, and at the different divisions. This pattern card can

then easily be duplicated by laying the card on paper, putting a pencil point through each of the holes, and subsequently connecting the points thus obtained.

Still another convenient way to save the trouble of drawing the axes a second time is to place a piece of tracing paper over the mounted drawing of the axes, and make the required drawing on the tracing paper.

Suppose we wish to represent the plane $1\ 2\ 3$. Obtain a projection of the parameters $a\ b\ c$. Draw a line through the points $\frac{1}{2}$ th of a or a of figure 2, Plate I., and $\frac{1}{2}$ of b or y of same figure. This is a line in the plane. Through the point $z = \frac{1}{3}$ rd of c draw a line parallel to the first line. We have now two parallel lines, as and qr , both in the required plane $1\ 2\ 3$, and these will indicate the lie of the plane. The drawing has, however, more meaning if $p\ q$ and $r\ s$ are drawn parallel to the dotted line yz . The drawing now represents four lines in the plane $1\ 2\ 3$. These lines *may* form the boundary of the plane, but we may imagine the plane as extending as far as we please beyond the boundary.

In the same figure. Plate I., figure 2, are represented the planes $1\ 2\ \bar{1}$ and $1\ 0\ 0$ drawn by the method above described.

It should be kept in mind by the student that in crystal forms, such for example as the octahedron, an edge of the form is produced by the intersections of two planes which meet together. Hence in drawing a crystal form, of which the indices of the planes are given, what we have to do is to draw in perspective the various edges formed by the intersections of the different planes.

In figure 3 of Plate I. is represented at bc the intersection of two of the planes (the $1\ 1\ 1$ plane and the $\bar{1}\ 1\ 1$ plane) of the octahedron. The plane $\bar{1}\ 1\ 1$ is shaded, while the plane $1\ 1\ 1$ is unshaded. In many cases the line of intersection of the two planes is obvious on looking at the indices. Thus, with the two planes $1\ 1\ 1$ and $\bar{1}\ 1\ 1$ of

figure 3, Plate I., noting that the last two indices are alike in the two planes, a line drawn from $\frac{1}{4}$ th of b to the $\frac{1}{4}$ th of c must lie in both planes, since these points are common. Such a line then represents the intersection of the two planes.

Before giving an example as an application of the previous remarks it may be well to state the meaning of the following terms :—

An axial plane is a plane containing two of the axes of the crystal. The plane XZ would be a plane containing the axes X and Z .

Positive octant. When the axes are drawn, then if planes pass through these axes, taken two and two together, the space about the origin is divided into eight portions, or compartments. In the usual drawings the top right-hand compartment is the positive octant. The other octants are sufficiently described as the right lower, left upper, left lower, back right upper, back right lower, &c.

Or they may be numbered in the way suggested by Professor Maskelyne, *Crystallography*, p. 16. This mode of numbering is indicated in figure 4, Plate I., where the axial planes are looked upon as dividing a cylinder into eight compartments. Looking down upon the cylinder the upper four compartments are numbered in the clock-wise direction, while the lower compartments are numbered in the counter-clockwise direction, the fifth compartment being diametrically opposite the fourth compartment.

EXAMPLE.—Make a drawing of the twenty-four faced trapezohedron from the following scheme of the various intersections of its planes.

Intersections in the axial plane XZ —

$$\begin{array}{cccc}
 a \left\{ \begin{array}{l} 1 \ 1 \ 2 \\ 1 \ 1 \ 2 \end{array} \right. & b \left\{ \begin{array}{l} 2 \ 1 \ 1 \\ 2 \ 1 \ 1 \end{array} \right. & c \left\{ \begin{array}{l} 2 \ 1 \ 1 \\ 2 \ 1 \ 1 \end{array} \right. & d \left\{ \begin{array}{l} 1 \ 1 \ 2 \\ 1 \ 1 \ 2 \end{array} \right. \\
 e \left\{ \begin{array}{l} 1 \ 1 \ 2 \\ 1 \ 1 \ 2 \end{array} \right. & f \left\{ \begin{array}{l} 2 \ 1 \ 1 \\ 2 \ 1 \ 1 \end{array} \right. & g \left\{ \begin{array}{l} 2 \ 1 \ 1 \\ 2 \ 1 \ 1 \end{array} \right. & h \left\{ \begin{array}{l} 1 \ 1 \ 2 \\ 1 \ 1 \ 2 \end{array} \right.
 \end{array}$$

Intersections in the axial plane X Y—

$$p \left\{ \begin{smallmatrix} 2 & 1 & 1 \\ 2 & 1 & \bar{1} \end{smallmatrix} \right. \quad q \left\{ \begin{smallmatrix} 1 & 2 & 1 \\ 1 & 2 & \bar{1} \end{smallmatrix} \right. \quad r \left\{ \begin{smallmatrix} \bar{1} & 2 & 1 \\ \bar{1} & 2 & \bar{1} \end{smallmatrix} \right. \quad s \left\{ \begin{smallmatrix} \bar{2} & 1 & 1 \\ \bar{2} & 1 & \bar{1} \end{smallmatrix} \right.$$

Intersections in the axial plane Y Z—

$$w \left\{ \begin{smallmatrix} 1 & 1 & 2 \\ \bar{1} & 1 & 2 \end{smallmatrix} \right. \quad x \left\{ \begin{smallmatrix} 1 & 2 & 1 \\ \bar{1} & 2 & 1 \end{smallmatrix} \right. \quad y \left\{ \begin{smallmatrix} 1 & 2 & \bar{1} \\ \bar{1} & 2 & \bar{1} \end{smallmatrix} \right. \quad z \left\{ \begin{smallmatrix} 1 & 1 & \bar{2} \\ \bar{1} & 1 & \bar{2} \end{smallmatrix} \right.$$

Intersections in the positive octant, but not in the axial planes—

$$a_1 \left\{ \begin{smallmatrix} 1 & 1 & 2 \\ 1 & 2 & 1 \end{smallmatrix} \right. \quad b_1 \left\{ \begin{smallmatrix} 2 & 1 & 1 \\ 1 & 2 & 1 \end{smallmatrix} \right. \quad c_1 \left\{ \begin{smallmatrix} 2 & 1 & 1 \\ 1 & 1 & 2 \end{smallmatrix} \right.$$

Looking at the indices of the intersection a , we note that the first and last index of the two planes is the same, hence their intersection is the line $1 \ 0 \ 2$, or x_1, z_2 , of figure 5, Plate I.; similarly that of b must be the line $2 \ 0 \ 1$, or x_2, z_1 , and so on with the intersections c, d, e, f, g, h , in the axial plane X Z. Similarly also with the intersections p, q, r, s in the axial plane X Y, and w, x, y, z in the axial plane Y Z.

As regards the intersections not in the axial planes, note, for example with a_1 , that the planes coincide in the first index, $x = \frac{1}{2}$ th of a , hence the intersection planes through x_1 , another point in the intersection is indicated at the intersection of w and x , hence the intersection is a_1 (a thick line), and its continuation (a thin line) to x_1 . The remaining intersections are not further described, as they can easily be understood from what has preceded.

Note that the intersections drawn indicate the geometrical figure, enclosed by the various planes constituting the crystal, and it is only necessary to thicken those lines which enclose the figure, as shown in the drawing.

The student will find it desirable to work out the drawing of figure 5, Plate I., on a large scale, following the description step by step.

Zone Axis.—The term zone is already understood (see Lesson I., p. 10). Now a line drawn through the origin

parallel to one of the edges of a zone is called the axis of that zone. For example, the line $to't'$ (figure 6, Plate I.) is a line drawn through the origin, and parallel to the intersection of the faces p, q, r, s , &c., constituting a zone, hence $to't'$ is the axis of the zone, or the zone axis, whichever way we like to express it.

In many cases, especially where the crystal is indicated by a number of zones, it is easier to calculate an equation for the zone axis, and make use of this equation to draw a line to which all intersections in the zone are parallel. At present it is proposed only to show how, having given the indices of any two planes, a line parallel to their intersection may be drawn.

Let it be required to draw a line parallel to the intersection of the planes $2\ 1\ 1$ and $1\ 2\ 1$.

Write out the two pairs of indices twice in two lines, one under the other, as in A.

A	$\begin{array}{cccccc} 2 & 1 & 1 & 2 & 1 & 1 \\ 1 & 2 & 1 & 1 & 2 & 1 \end{array}$	B	$\begin{array}{ccccc} 2 & 1 & 1 & 2 & 1 & 1 \\ 1 & 2 & 1 & 1 & 2 & 1 \end{array}$
---	--	---	---

Now strike out the indices to the extreme right and left, as at B, and with the remaining two rows of four figures proceed to multiply the first figure of the first row into the second figure of the second row, and subtract from this the second figure of the first row, multiplied into the first figure of the second row, when we have the first zone index; next multiply the second figure of the first row into the third figure of the second row, and subtract from this product the third figure of the second row multiplied into the second figure of the second row; this gives the second index. The remaining figures similarly treated give us the third index.

At B the figures to be multiplied first are connected by continuous lines, and the figures to be multiplied and subtracted are connected by broken lines.

Carrying out this process we have

$$\text{First index} = 1 \times 1 - 1 \times 2 = \bar{1}$$

$$\text{Second „} = 1 \times 1 - 2 \times 1 = \bar{1}$$

$$\text{Third „} = 2 \times 2 - 1 \times 1 = 3$$

Hence the zone indices are $\bar{1} \bar{1} 3$.

To make use of these indices to draw the required intersection, set off on the axis X (Plate I., figure 7) any convenient length, such as $Ox = 1/n$ th of $\bar{a}$, from x draw parallel to the axis Y the length $xy = 1/n$ th of $\bar{b}$, and from y draw parallel to the axis Z the length $yz = 3/n$ of c . From z draw the dotted line zO . This dotted line is the direction of the zone axis. Now the required intersection passes through the point c , since the last index is 1, and is common to both planes, hence the line rs parallel to zO passing through c is the perspective drawing of the required intersection.

It will be noticed that this line corresponds to the line b_1 of figure 5, Plate I., obtained by the method first described.

In the figure (7, Plate I.) Ox is taken $\frac{1}{3}$ rd of $\bar{a}$, xy is taken $\frac{1}{3}$ rd of $\bar{b}$, and yz is taken $\frac{1}{3}$ rd of c .

Representation of the Edges of Crystals in Plan and Elevation.—The drawing of the axes described at page 29 represents these axes as already stated in isometric perspective. Refer for a moment to the drawings of the cube in different positions, Plate I., figure 1. At B we have the cube in isometric perspective, and the termination of the axes are indicated by the dots near the letters x, y, z .

At C_1 we are looking directly at the axis y . Keeping the eye fixed, let the cube be turned clockwise round the vertical axis z , and afterwards turned round the horizontal axis x , so as to bring the top face into view. We then have, if the turning round the vertical axis is $18^\circ 26'$,

and the turning round the horizontal axis is $9^{\circ} 28'$, the projection of the cube as in B, Plate I., and the projection of the axes of figure 9, Plate IV.

To make the plan of a crystal having rectangular axes, we place the crystal in imagination so that the axis Z is vertical, and the axes X and Y are in the plane of the paper, and then project on to the paper the edges as they would appear to an observer at a very great distance above the crystal.

These points being understood, we can proceed to make a plan of a crystal when we know the system and the various poles.

Let the parameters be of equal length, and at right angles to each other, as in the regular system. Then the plan of the parameters, or their appearance when the eye is vertically above one of them, which for convenience sake we will call c , is obviously the cross $a \bar{a}$, $b \bar{b}$, as in figure 8, Plate I., in which $a \bar{a} = b \bar{b}$, and is at right angles to it. The projection of the parameter c is merely the intersection of $a \bar{a}$ and $b \bar{b}$, but in imagination we can suppose the parameter c standing out above the paper to a height equal to the length $c a$ or $c b$.

Suppose we wish to represent the intersection of the planes 121 and 211 . The plane 121 cuts the parameter c at its extremity, it cuts the parameter b at half its length, and the parameter a at its extremity, hence the trace of the plane on the paper (figure 8, Plate I.) will be the line ag , similarly the trace of the plane 211 will be the line fb , and since both planes pass through c , the projection of their intersection will be the line cr .

Take another case in which the index for c is different for the two planes, for example, the planes 123 and $1\bar{1}2$. Here we must, in order that both planes shall pass through a known point c , make the last index of each plane 1. This we do by converting the symbols into Weiss's notation (see page 24, last lesson), when we have for the plane 123 the

equivalent plane $3a \frac{2}{3}b c$, and for $1 \bar{1} 2$ the equivalent plane $2a \bar{2}b c$. Now draw a line from h ($ch = 3a$) to k ($ck = \frac{2}{3}b$), and we have in this line the trace of the plane $1 2 3$. For the trace of the plane $2a \bar{2}b c$ (Weiss) draw a line from l ($cl = 2a$) to m ($cm = -2b$), and continue the lines until they intersect, and through the point of intersection draw cs , when we have the required projection.

Or we may find the zone indices by the method of page 33, and apply this. Thus, to draw the intersection of the planes $1 2 3$ and $1 \bar{1} 2$, find the zone indices thus—

$$\begin{vmatrix} 1 & 2 & 3 & 1 & 2 \\ 1 & 1 & 2 & 1 & 1 \end{vmatrix} \begin{vmatrix} 3 \\ 2 \end{vmatrix} = 4 - 3, 3 - 2, 1 - 2 = 1 \bar{1} \bar{2}$$

Now run the pencil from c to a , this represents $1a$, from a draw $at = 1b$, and now, joining t and c , we have the required projection. It will be noticed that the method of proceeding is the same as where the axes are projected in perspective, only here we have the axis c reduced to a point, and all lines parallel to c are also points.

Example.—Make a plan of the form $[1 1 2]$ of the regular system from the intersections given at page 31 and 32. See also Plate I., figure 5.

Project the parameters $a \bar{a}, b \bar{b}$ of equal length, see Plate I., figure 9. The projections of the intersections $a, b; w, x$ (Plate I., figure 5) evidently coincide with the parameters ca and cb respectively. For the intersections p, q in the axial plane XY , that is, in the plane of the paper, we find these, on drawing the traces of the planes $2 1 1$ and $1 2 1$, that is, the lines fb and ga , figure 8, Plate I. The direction cr , figure 8, gives us the direction of the edge or intersection b_1 in figure 9. As regards the remaining intersections in the positive octant, that is, the intersections a_1 and c_1 , find the zone indices. That of a_1 is $\bar{3} 1 1$, and of c_1 it is $1 \bar{3} 1$. From these numbers draw the

dotted lines cz and cy of figure 9. Then the edge a_1 is parallel to cz , and the edge c_1 is parallel to cy . Having drawn the projection of the edges in the positive octant, the drawing may be completed by symmetry.

EXERCISES.

41. Having the projection of the axes (Plate IV., figure 9), draw by inspection (see page 32) each of the following intersections:—

$$a \begin{cases} 1 & 1 & 1 \\ 1 & 1 & \bar{1} \end{cases}$$

$$b \begin{cases} 1 & 1 & 1 \\ \bar{1} & 1 & 1 \end{cases}$$

$$c \begin{cases} 1 & 1 & 1 \\ 1 & \bar{1} & 1 \end{cases}$$

Note that the above intersections give the triangular face of the octahedron in the positive octant.

42. To the drawing as obtained in 41 add each of the following lines indicating intersections:—

$$d \begin{cases} 1 & 1 & 2 \\ 1 & 2 & 1 \end{cases}$$

$$e \begin{cases} 2 & 1 & 1 \\ 1 & 2 & 1 \end{cases}$$

$$f \begin{cases} 1 & 1 & 2 \\ 2 & 1 & 1 \end{cases}$$

This should give a drawing of one octant of the triakis octahedron; see figure 42, Lesson VI.

43. Make a drawing of a cube from the following pairs of intersections:—

$$h \begin{cases} 1 & 0 & 0 \\ 0 & 1 & 0 \end{cases}$$

$$i \begin{cases} 0 & 1 & 0 \\ 0 & \bar{1} & 0 \end{cases}$$

$$a \begin{cases} 0 & 1 & 0 \\ 0 & 0 & 1 \end{cases}$$

$$c \begin{cases} 0 & 0 & 1 \\ 0 & \bar{1} & 0 \end{cases}$$

$$b \begin{cases} 0 & 0 & 1 \\ \bar{1} & 0 & 0 \end{cases}$$

$$f \begin{cases} 1 & 0 & 0 \\ 0 & 0 & 1 \end{cases}$$

$$c' \begin{cases} 0 & 1 & 0 \\ 0 & 0 & \bar{1} \end{cases}$$

$$g \begin{cases} 1 & 0 & 0 \\ 0 & \bar{1} & 0 \end{cases}$$

$$b' \begin{cases} 1 & 0 & 0 \\ 0 & 0 & \bar{1} \end{cases}$$

NOTE.—The drawing when made should correspond to the drawing of the cube, Plate I., figure 1 B, the letters in the exercise corresponding to letters indicating the edges of the cube in 1 B.

44. Make a drawing of the axial planes XY , XZ , and YZ , without the cylindrical enclosure of figure 4, Plate I.

45. Three zones, A, B, C, contain the following planes :

A	B	C
$a \ 1 \ 0 \ 0$	$a \ 1 \ 0 \ 0$	$b \ 0 \ 1 \ 0$
$b \ 0 \ 1 \ 0$	$c \ 0 \ 0 \ 1$	$c \ 0 \ 0 \ 1$
$a^1 \ \bar{1} \ 0 \ 0$	$a^1 \ 1 \ 0 \ 0$	$b^1 \ 0 \ \bar{1} \ 0$
$b^1 \ 0 \ \bar{1} \ 0$	$c^1 \ 0 \ 0 \ \bar{1}$	$c^1 \ 0 \ 0 \ \bar{1}$

Draw the axis of each zone after the manner described at page 34, and note that the three lines obtained correspond to those of the axes.

46. Draw by help of the zone equation the axis of each of the following zones :—

A	B	C	D
$1 \ 1 \ 0$	$\bar{1} \ 1 \ 0$	$1 \ 1 \ 0$	$\bar{1} \ 1 \ 0$
$0 \ 1 \ 1$	$0 \ 1 \ 1$	$1 \ 0 \ 1$	$0 \ 1 \ \bar{1}$
$\bar{1} \ 0 \ 1$	$1 \ 0 \ 1$	$0 \ \bar{1} \ 1$	$1 \ 0 \ \bar{1}$
$\bar{1} \ \bar{1} \ 0$	$1 \ \bar{1} \ 0$	$\bar{1} \ \bar{1} \ 0$	$1 \ \bar{1} \ 0$

With this and the preceding exercise note that any two planes in the same zone may be used to obtain the equation, except a plane and its opposite. For example, in zone A the pairs of planes $1 \ 1 \ 0$ and $\bar{1} \ \bar{1} \ 0$ merely give $0 \ 0 \ 0$ as the zone equation, while all the other pairs give $1 \ \bar{1} \ 1$. Note that the zone axes of this exercise correspond to the four diagonals of the cube.

47. Make a plan of the octahedron projected on to a plane, passing through the axial plane X Y. (Note that the drawing results in a square with its two diagonals.)

48. Make a plan of the triakis octahedron from data given in questions 41 and 42.

LESSON V.

Spherical Projection.

THE method of drawing crystals given in the last lesson is rather tedious, but the method of representation to be now described, that of spherical projection is particularly simple, easy of execution, and conveys more information respecting a crystal than any perspective drawing possibly can do, hence the student should give close attention to the lesson and the exercises which follow.

Since in a crystal the angles are constant, whatever variation there may be in the size of the planes, we may in imagination separate a pair of opposite planes, and make them approach each other, or recede, just as we please, so long as the planes of each pair are kept parallel to their original positions.

Take now a sphere and a crystal, a cube for example, and move the sides of the cube to and fro until each of the

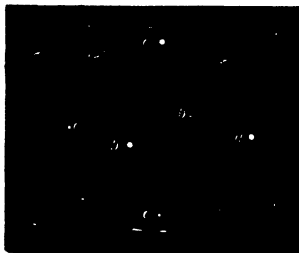


Fig. 14.

six sides touches the sphere, and imagine a dot at each point of contact, as in figure 14. There are now six dots on the sphere $a, \bar{a}; b, \bar{b}; c, \bar{c}$; these dots corresponding as it were to a north and south pole, $c, \bar{c}$, the dots $a, \bar{a}, b, \bar{b}$ being on the equator.

Let us now examine the sphere quite apart from the crystal, as in figure 15. In the first place we note that the

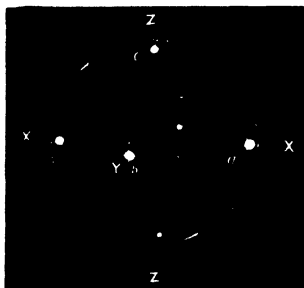


Fig. 15.

dots indicate the position of the terminations of the axes of the cube; again we notice that the dots (*poles*) are contained in three great circles,* each circle corresponding to a zone on the crystal. Again, the angles measured from dot to dot along the great circles corres-

pond to angles between normals to faces of the crystal.

Thus, for example, the distance between $a\ b$ on the sphere is 90° , corresponding to the normal angle between the faces a and b of the cube.

The next point to consider is how to represent on paper the dots or poles on the sphere.

In the last lesson we spoke of a drawing as the representation of an object as it appears on a piece of glass held between the eye and the object. Now, in making a

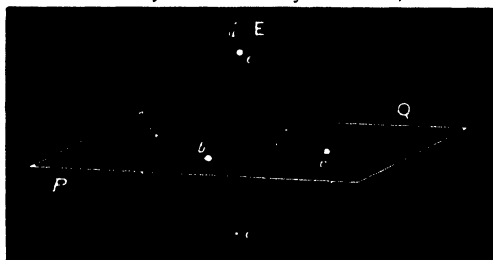


Fig. 16.

* A *great circle* of a sphere is a circle drawn on the sphere such that the plane of the circle passes through the centre of the sphere. All other circles drawn on the sphere are *small circles*.

drawing of the dots on the sphere, a piece of glass, extremely thin, is supposed to pass in a horizontal plane through the centre of the sphere, and the eye is placed on the sphere itself vertically above the centre of the sphere, as represented in figure 16, where PQ is the piece of glass, and E the eye. Properly the eye should touch the sphere at the dot c instead of above it, as it appears in the drawing.

The sphere itself is regarded as of a transparent material, so that the dots upon its exterior can be seen when looking into the inside of the sphere.

Now it is pretty clear that if we draw a circle to represent a disc, produced by the intersection of the sphere, and the glass or plane of projection, that is, the circle $a b \bar{a}$ of figure 16, the appearance presented to the eye at E , placed vertically above the centre of the glass disc, will be as in figure 17, and this figure (17) is a map of the poles of the cube (or any crystal bounded by six planes at right angles to each other) in stereographic spherical projection.

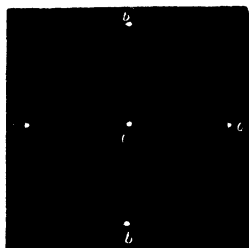


Fig. 17.

It is usual in stereographic projection of crystals to represent only what would be seen on the lower half of the sphere, though it is sometimes a convenience to show the poles on the upper part of the sphere, but this point may be deferred for the present.

Take the model of the octahedron, Plate II., figure D. Imagine a sphere inside it; the faces will touch the sphere in eight points. The sphere, when mapped, will show four of these points in positions, shown at o_1 , o_2 , o_3 , and o_4 of figure 19, page 42.

Intersection of the Planes of Symmetry with the Surface of the Sphere.—The planes of symmetry passing through the centre of the sphere will obviously produce, by their intersections with the surface of the sphere, a series of great circles. In the most complex case, viz., that of the cubic system, there are nine planes of symmetry, and the picture of their intersections on the sphere is as in figure 18.

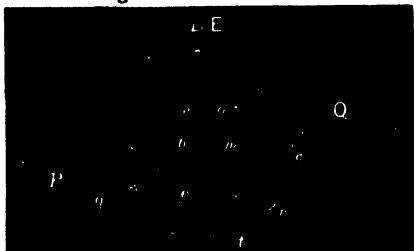


Fig. 18.

One of the planes, PQ , forms the plane of projection, and the great circle formed by its intersection with the sphere is the circle $am b$. If PQ is horizontal, and the eye vertically above the centre of the circle, the appearance of $am b$ is the circle $am_1 b m_2 \bar{a} \bar{m}_1 \bar{b} \bar{m}_2$ of figure 19.

The four vertical planes produce the circles ca , cm , cb , and cs , of figure 18, and to the eye at E give, so far as the



Fig. 19.

lower part of the sphere is concerned, the straight lines $ac \bar{a}$, $m_1 c \bar{m}_1$, $bc \bar{b}$, $m_2 c \bar{m}_2$ of figure 19. The oblique planes produce the circles ap , bn , ae , and br , of figure 18, and these circles, as viewed by the eye at E , will appear, as regards the lower part of the sphere,

as the arcs $a m_6 \bar{a}$, $b m_5 \bar{b}$, $a m_4 \bar{a}$, $b m_3 \bar{b}$. We have now in figure 19 a complete map of the nine planes of symmetry of the regular system.

The student should thoroughly realize the picture of the sphere with the intersections of the planes of symmetry passing through it, represented in figure 18. He would, in fact, in order to understand the intersections better, find it an advantage to mark these circles in ink on a child's ball. He will then note that the arc $c b$ is a quarter of the circle, or 90° , as also are the arcs $a b$, $c a$, $c m$, $b n$, $p a$. The arcs $a m$, $m b$, $b p$, $p c$, $c n$, $n a$, are each 45° . Having realized these facts in reference to the sphere itself, he will easily see that in the projection, figure 19, the arcs $a c$, $b c$, $a b$, $m_1 c$ are each 90° , while the arcs $a m_1$, $m_1 b$, $b m_4$, $m_4 c$, $c m_3$, $m_3 a$, are each 45° .

To Draw a Map of the Planes of Symmetry of the Regular System.—With c as centre, figure 19, draw the circle $a m_1 b$. Draw the diameters $a c \bar{a}$ and $b c \bar{b}$ at right angles to each other. Set one leg of the compasses at a , and, extending the other leg to b , draw the arc $b m_5 \bar{b}$, with same radius draw from the points b , $\bar{a}$, $\bar{b}$, the arcs $\bar{a} m_6 a$, $\bar{b} m_5 b$, $a m_4 \bar{a}$, and through the intersections of these arcs at o_1 , o_2 , o_3 , o_4 draw the diameters $m_1 \bar{m}_1$ and $m_2 \bar{m}_2$. This completes the map.

The spherical projections of the planes of symmetry characteristic of each system are given in the next Lesson.

It may be mentioned here that in the stereographic projection of the sphere all circles, whether "great" or "small," are represented either by straight lines or arcs of circles. Hence an accurate map of points on a sphere can be made very readily, and zone circles be easily drawn through any two points in the manner about to be explained.

Having given the Normal Angles between the Poles in any Zone of a Crystal to make a Map of that Zone.

It will be remembered (see Lesson I., page 10) that a zone on a crystal consists of a series of three or more planes whose intersections are parallel.

Let $A, M_1, B, M_2, \bar{A}, \bar{M}_1, \bar{B}, \bar{M}_2$, figure 20, be section

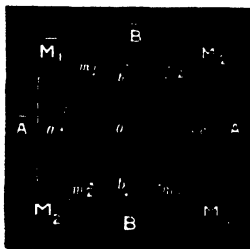


Fig. 20.

of a crystal at right angles to a zone axis, A, M_1, B , &c., being faces in the zone. Draw a circle inside this section to represent a great circle of the sphere, and now let the planes, extended if necessary, move parallel to themselves until they touch the circle. Then the points of contact or poles will be the dots $a, m_1, b, m_2, \bar{a}, \bar{m}_1, \bar{b}, \bar{m}_2$, marked on the circle. The

way in which the planes A and $\bar{M}_2$ are supposed to move up are represented by dotted lines, and the normals to these planes drawn from the centre o of the circle are represented in the drawing. Now let us consider how to represent this zone on the plane of projection PQ , figure 18, under three circumstances.

(1) *The zone circle is horizontal, and lies in the plane of projection.*

The zone circle in this case will correspond to the circle $am b$ of figure 18. To the eye at E then the picture of the poles is a circle with dots upon it, at angles corresponding to the normal angles between the faces of the crystal. In fact, expunge from figure 20 all but the circle with the dots a, m_1, b , &c., upon it, and we have the required map.

(2) *The zone circle is vertical, that is, at right angles to the plane of projection.*

The zone circle in this case will correspond to one of the

circles $a n c$, $m o c$, &c., of figure 18. We will suppose it to correspond to the circle $a n c$.

We have now to imagine the zone $a m_1 b$, &c., of figure 20 placed in the position of the great circle, $a c n$ of figure 18, and we want to know how the points a , m_1 , b , m_2 , $\bar{a}$ will appear to the eye at E when this change has

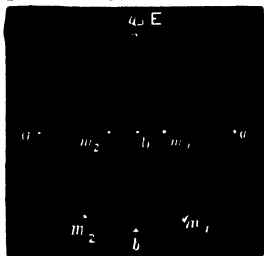


Fig. 21.

been made. The circle $a m_1 b$, &c., of figure 21 represents the zone circle with its poles, a , m_1 , b , m_2 , $\bar{a}$, turned into the vertical position. The diameter of the circle of projection appears now as the straight line $a \bar{a}$, and to the eye the projection of the poles a , m_1 , b , m_2 , $\bar{a}$ on the plane of projection will evidently be at the points a , m'_1 , b' , m'_2 , $\bar{a}$. Having found the position of these poles along a diameter of the circle of projection, we have now merely to expunge the construction lines (the dotted lines) of figure 21, together with the letters and dots at m_1 , b , m_2 , and we have a map of the required zone.

(3) *The zone circle is oblique, the angle between the oblique zone circle and the circle of projection being given.*

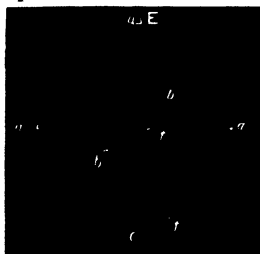


Fig. 22.

Let $a b \bar{a}$, figure 22, represent the circle of projection, $a t \bar{a}$ a circle at right angles to the plane of projection, and $b t b$ any oblique zone circle, making an angle $a t$ with the plane of projection.

It is required to represent in the plane of projection the zone circle $b t \bar{b}$.

To the eye in the position represented the point t will appear in the position t' along the diameter $a\bar{a}$.

We know now three of the points of the zone $b\bar{t}\bar{b}$ in the circle of projection, viz., $b\bar{b}$, the extremities of a diameter of the zone, and also the position of the point t as indicated at t' . Drawing the arc $b\bar{t}'\bar{b}$ of figure 22, we have a *picture* of the required zone on the plane of projection.

To make the map then of the zone circle, draw first the circle of projection PQ , figure 23, then mark the position of the extremities of the given diameter $b\bar{b}$. Draw $a\bar{a}$ at right angles to a straight line joining $b\bar{b}$. From a measure off at , the given angle between the zone circle and the circle of projection. Join $\bar{b}t$, intersecting $a\bar{a}$ at t' ,

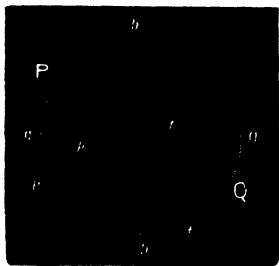


Fig. 23.

strike an arc through $b\bar{t}'\bar{b}$, and we have the required projection.

It will be noticed that so far in this third case we have merely shown how to map the oblique zone circle. To mark the position of poles on this circle requires further consideration. To map the poles we must first find the projection of the *pole* of the great circle $b\bar{t}\bar{b}$ of figure 22, that is, the projection of a point which is 90° from every point of the great circle $b\bar{t}\bar{b}$, just as the North Pole is 90° from every point of the equator. To find the required projection of the pole, we measure 90° from t , figure 23, in the circle of projection towards $\bar{a}$, when we obtain the point p . Join $\bar{b}p$, intersecting $a\bar{a}$ at p' . The point p' is the projection of the required pole.

Let us see, now we have the zone circle drawn, and also the position of the pole, how to represent poles which are

given on the zone circle. As before, let the poles $a, m_1, b, m_2, \bar{a}$, of figure 20, be those which are to be mapped.

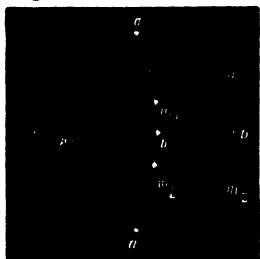


Fig. 24.

Having drawn the projection of the zone circle, and found its pole as just described, mark off points a, m_1, b, m_2 , &c., at the given angles along the circle of projection, as represented in figure 24. Now from p' , the pole of the circle, draw the lines $p'a, p'm_1, p'b$, &c. Then the intersections $a, m'_1, b, m'_2, \bar{a}$

are the required poles.

It may here be stated that in all cases when we have an arc drawn on the plane of projection, then to measure off any angle on the great circle to which the arc refers, we find the pole of the great circle, and from the pole draw lines to points on the circle of projection, the points on the circle of projection being separated by the required angle. Thus, in case 1, page 44, the centre o of the circle $a m_1$, figure 20, is the pole of the circle $a m_1$. Again, in case 2, the position of the eye, figure 21, marks the pole of the circle $a m'_1 b' m'_2 \bar{a}$ (its projection being a straight line), and lastly, in the third case, p' , figure 24, is the pole of the circle $a m'_1 b' m'_2 \bar{a}$.

We may now proceed to apply our knowledge of spherical projection to the mapping of a crystal. This will be best understood by an example or two.

NOTE.—A zone is sufficiently indicated when two of its poles are mentioned, provided these poles are not extremities of a diameter. Thus, the zone A in the following example may be spoken of as the zone $a m_1$.

EXAMPLE 1.—Make a spherical projection of a crystal of barytes (prismatic system) from the following measurements.

Take the zone A or $a m_1$ as circle of projection (see Plate II., figures 1 and 1a):—

A	B	C
$a m_1$ $50^\circ 50'$	$a o_1$ $37^\circ 18'$	$b u_1$ $31^\circ 50'$
$a b$ 90°	$a c$ 90°	$b c$ 90°
$a m_2$ $129^\circ 10'$	$a o_2$ $142^\circ 42'$	$b u_2$ $148^\circ 10'$
$a \bar{a}$ 180°	$a \bar{a}$ 180°	$b \bar{b}$ 180°
$a \bar{m}_1$ $50^\circ 50'$		
$\bar{a} b$ 90°	D ₁	D ₂
$\bar{a} m_2$ $129^\circ 10'$	$m_1 z_1$ $25^\circ 42'$	$m_2 z_2$ $25^\circ 42'$
$\bar{a} a$ 180°	$m_1 c$ 90°	$m_2 c$ 90°
	$m_1 z_3$ $154^\circ 18'$	$m_2 z_4$ $154^\circ 18'$
	$m_1 \bar{m}_1$ 180°	$m_2 \bar{m}_2$ 180°

Since the system is prismatic, draw the three planes of symmetry, $a b$, $b c$, and $a c$, Plate II., figure 1, and mark the poles a , m_1 , b , &c., on the circle of projection, by measurement with a protractor, making $a m_1$ $50^\circ 50'$, $a b$ 90° , and so on, round the zone A. Since c is 90° from a (see zone B), and also 90° from b (see zone C), it is obvious that c is at the centre of the circle. Now, on the zone $a c$, measure $a o_1$ $37^\circ 18'$ as described (page 45), that is, by measuring $37^\circ 18'$ on the circle of projection from a ; then, from the point o thus obtained, draw the line $\bar{b} o$, cutting the zone $a c$ at o_1 . Then o_1 will be marked in its proper place. By symmetry mark o_2 at an equal distance on other side of c , and we have the zone B mapped. By similar method lay down the zone C, marking the poles u_1 and u_2 . As regards the zone D₁, join $m_1 c \bar{m}_1$ by a dotted line, this gives the trace of the zone circle D₁, and we have to measure a distance $m_1 z_1$ of $25^\circ 42'$ along this line. To do this draw $c p$ at right angles to $m_1 c \bar{m}_1$, meeting the circle of projection at p . Measure from $\bar{m}_1$ a distance of $25^\circ 42'$ and join the point thus found with p by the dotted line passing through z_3 . Measure on the opposite side of

c the distance $c z_1 = c z_3$, and we now have the position of z_1 and z_3 marked. By symmetry the poles z_2 and z_4 on the zone D_2 are marked. Now, rubbing out the construction lines, we have the complete map.

The drawing 1*a* of Plate II. will help the student to see the connection between the crystal and the projection. The letters on the drawing 1*a*, indicating the faces of the crystal, correspond to those on the projection.

EXAMPLE 2.—A mineral of the prismatic system has the following zones. The poles in the positive octant only are given. Take zone A as the plane of projection (see Plate II., figure 2):—

A		C	
$a n_1$	$32^\circ 27'$	$b c$	90°
$n_1 m_1$	$19^\circ 22'$		
$m_1 b$	$38^\circ 11'$		
B		D	
$a o_1$	$37^\circ 44'$	$b z_1$	$44^\circ 50'$
$o_1 c$	$52^\circ 16'$	$z_1 o_1$	$45^\circ 10'$

Since the system is prismatic, draw at once the three planes of symmetry $a b$, $b c$, $c a$, Plate II., figure 2, and proceed to mark the poles a , n_1 , m_1 , b , and also on the same zone by symmetry the poles m_2 , n_2 , $\bar{a}$, $\bar{n}_1$, $\bar{m}_1$, $\bar{b}$, $\bar{m}_2$, $\bar{n}_2$, which may be assumed present, though only one-quarter of the zone is given. From zones B and C we note that c is at the centre of the projection.

The pole o_1 is on the zone $a c$. Set off the distance $a o_1$ ($37^\circ 44'$) on the circle of projection as shown, and from the point P thus obtained draw the dotted line $\bar{b} o_1 P$, crossing the zone $a c$ at o_1 . Then o_1 is the position of the pole o_1 . Now draw a great circle through $b o_1 \bar{b}$ by finding on trial a point Q on the line $a \bar{a}$, such that by putting one leg of the compasses at Q an arc of a circle will pass through $b o_1 \bar{b}$. Draw this arc, and we have

the projection of the zone circle D . As regards the pole z_1 , situated on this arc, we note that measuring from b it is $44^\circ 50'$ along the circle $b o_1 \bar{b}$, and we have to find this distance. To do this first find the pole R of the great circle $b o_1 \bar{b}$, by measuring 90° from P along the circle of projection, and from the point S thus found draw the dotted line $S \bar{b}$, cutting $a \bar{a}$ at R , and we have R as the pole of the zone circle $b o_1 \bar{b}$. Now measure a point T $44^\circ 50'$ from b , join TR by a dotted line, and where this line crosses the arc $b o_1 \bar{b}$ we have the position of the pole z_1 . The poles o_2, z_2, z_3, z_4 may now be put in by symmetry, and the map is complete.

EXERCISES.

51. A crystal of the prismatic system consists of the following zones at right angles to each other.

$a m_1$	$31^\circ 24'$	$a k_1$	$54^\circ 8'$	$b y_1$	$29^\circ 21'$
$m_1 b$	$58^\circ 36'$	$k_1 c$	$35^\circ 52'$	$y_1 c$	$60^\circ 39'$
$b m_2$	$58^\circ 36'$	$c k_2$	$35^\circ 52'$	$c y_2$	$60^\circ 39'$
$m_2 a'$	$31^\circ 24'$	$k_2 a'$	$54^\circ 8'$	$y_2 b'$	$29^\circ 21'$

Make a spherical projection of the crystal projecting on the zone $a m_1$.

52. On the map you have now drawn draw a zone circle passing through the poles b , k , b' . Find the pole of this circle, and mark on this circle a pole p , which is $54^\circ 14'$ from k towards b , and fill up by symmetry the poles p_1, p_2, p_3 .

53. A crystal of gypsum (oblique system) has the following zones at right angles to each other.

$a d$	$52^\circ 16'$	$a m_1$	$34^\circ 19'$
$d \bar{a}$	$127^\circ 44'$	$m_1 b$	$55^\circ 41'$
$\bar{d} \bar{d}$	$127^\circ 44'$	$b m_2$	$55^\circ 41'$
$\bar{d} a$	$52^\circ 16'$	$m_2 a'$	$34^\circ 19'$

Make a map of the crystal projecting on the zone $a d$. Note that in this map b will be at the centre of the circle of projection instead of c , as is usual in other systems.

54. On the map of example 53 draw a zone circle through the poles $d_1, b, \bar{d}$, and on the circle thus obtained mark a pole l between b and a , and at $71^\circ 54'$ from b .

55. Fit the model of gypsum together (Plate III, L.), and study the model along with your map. You will note that the model does not contain either the pole d or the pole a , but it does contain the other poles.

56. Make a map of a crystal of nickel sulphate (tetragonal system) having the following five zones. Project on the zone A. The zones A, B, C are at right angles to each other. The zones D and E are also at right angles to each other, and each make an angle of 45° with the zones B and C respectively.

A	$a a$	90°	B	$a c$	90°	D	$o_2 t_2$	$16^\circ 14'$	$16^\circ 14'$	E	$t_2 c$	$53^\circ 25'$	$53^\circ 25'$
	$a_1 \bar{a}$	90°		$c \bar{a}$	90°		$t_2 c$	$53^\circ 25'$			$c t_2$	$53^\circ 25'$	
	$\bar{a} \bar{a}_1$	90°		$a_1 c$	90°		$c t_2$	$53^\circ 25'$			$t_2 o_2$	$16^\circ 14'$	$16^\circ 14'$
	$\bar{a}_1 a$	90°		$c \bar{a}_1$	90°		$t_2 o_2$	$16^\circ 14'$			$o_2 t_2$	$16^\circ 14'$	

57. Compare the map of nickel sulphate with the model of the crystal as made from the net of Plate III, N. Note that the poles a, a_1 are not present in the model. The other poles, however, are present in the model.

LESSON VI.

Interpretation of a Spherical Projection. Zones and their Intersections. Form.

THE student is now sufficiently familiar with spherical projection to form in his mind the appearance of a crystal form from its spherical projection, and may proceed to apply the projection to yield further information.

Look at figure 25, which represents the sphere with the zone circles of symmetry of the regular system marked

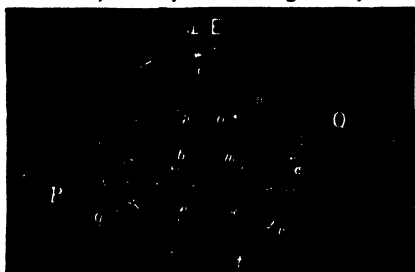


Fig. 25.

upon it, with the position PQ of the plane of projection, and at the same time compare with it figure 26.

In figure 25 the axes pass through the points $a\ b\ c$, and, as in the regular system, these axes are of equal lengths,



Fig. 26.

we have in the projection (figure 26) the lateral axes represented by the lines $a\ \bar{a}$ corresponding to the axis X , $b\ \bar{b}$ corresponding to the axis Y , while the vertical axis Z is foreshortened, and is represented by the point c , the intersection of $a\ \bar{a}$, $b\ \bar{b}$.

A pole situated at a (figure 26) conveys the idea of a plane perpendicular to the paper, and parallel to $b\bar{b}$ and $c\bar{c}$, that is, a plane which cuts the axis X , but which is parallel to the other two axes, hence its symbol is 1 0 0, similarly b is 0 1 0, and c is 0 0 1.

Take now the pole m of figure 25, represented separately as m_1 in figure 27. The point m_1 conveys the

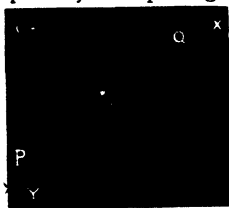


Fig. 27.

idea of a plane perpendicular to the paper, and at right angles to the radius cm_1 . The plane m_1 is therefore parallel to the axis Z , and its last index will consequently be 0. Draw a line PQ at right angles to cm_1 to represent the trace of the plane, and note that this plane cuts the axes X and Y at equal distances from the origin, hence, knowing that its last index is 0, it follows that the symbol of the m_1 plane must be 1 1 0.

Take now a pole h (figure 28) between m_1 and a . Draw PQ , the trace of the plane, on the paper, and note that while the plane is parallel to the Z axis it cuts off different lengths from X and Y . In the figure $OX = cX$ is $\frac{1}{2}$ of $OY = cY$, hence the symbol for this plane is 2 1 0.



Fig. 28.

In this manner we may by construction find the symbol for any pole whose plane is parallel to one of the axes, when we have given the number of degrees the pole is from the 1 0 0 plane, from the 0 1 0 plane, or from the 0 0 1 plane, or, on the other

hand, when we have the symbol of any plane having 0 as its last index, we may find its position on the plane of projection, and ascertain the number of degrees the pole is from the 1 0 0 plane.

The pole m_1 then indicates a plane 1 1 0, h a plane 2 1 0, and if there were a pole nearer to a than h (figure 28), it is easily seen that its symbol will be 3 1 0, 4 1 0, or some form $h k 0$, in which h is greater than k . Also with a plane nearer to b than m_1 its symbol will be 1 2 0, 1 3 0, or some form $k h 0$, in which h is still greater than k .

Now, suppose the plane 2 1 0 of figure 28, of which the trace is PQ , to move over the sphere at right angles to, but always touching, the great circle $h x y c$. As the plane moves it will be noticed that while the *relative* lengths of the axes X and Y , which the plane cuts off, remain the same, it is no longer parallel to the Z axis, so that the last symbol, instead of being 0, will have a definite value. Suppose, for example, that when the plane has reached x it cuts off from the axis Z the same length that it does from the axis Y , then the last index, and the middle index, will have the same value, but the first index will be double the second, hence the plane x would have a symbol 2 1 1. When the plane reaches y it cuts off a shorter length of the axis Z , which means that the last index will be greater, but the ratio of the first and second still remains the same, viz., 2 : 1; hence the symbol for the plane might be 2 1 2, 2 1 3, &c., or have a form 2 1 l , in which l keeps increasing as the plane moves from x towards c .

Again, let the plane move from x (in which place it cuts off equal lengths of the axes Y and Z) towards h . As it moves the length cut off from Z keeps getting greater and greater, and therefore the last index keeps getting less and less, but, as before, the ratio of the intercepts on X and Y remain as before in the ratio of 2 : 1, hence the symbol will be 2 1 l , in which l is now less than unity. Suppose, for example, the plane is at w , and that here the portion of

the axis Z cut off is double that cut off from the axis Y , then the last index is one-half that of the second, and the symbol then is $2 \ 1 \ \frac{1}{2}$, or, to avoid fractions, $4 \ 2 \ 1$. Similarly a pole v might have the symbol $6 \ 3 \ 1$.

From the above illustration the student will see that the symbols of all planes in a zone have two of their indices always in a constant ratio. In the example just given the ratio of the first index to the second is always $2 : 1$. In the first example, that where $m = 1 \ 1 \ 0$, $h = 2 \ 1 \ 0$, &c., and where the last index is 0, the statement is not so obvious, but the fact that the last index always remains 0 is sufficiently characteristic of the zone*.

Indices of a Pole which is at the Intersection of two Zones.—In figure 29 the pole o is at the intersection of two zones, one $m_1 \ c$, and the other $b \ d$. The

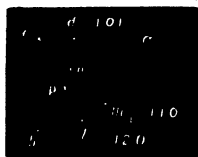


Fig. 29.

pole m_1 has the symbol $1 \ 1 \ 0$, and from what has been said all poles along the zone $m_1 \ c$ must have their first and second index equal. Again, the pole d has the symbol $1 \ 0 \ 1$, and all poles along the zone $d \ b$ similarly must have their first

and last index equal. Now o is in both zones, hence must satisfy the conditions that its first and second, and also its first and last, index shall be equal. It is obvious that the symbol $1 \ 1 \ 1$ is the only symbol which will satisfy both conditions, hence $1 \ 1 \ 1$ is the symbol of the pole o .

Again, if l of figure 29 is the $1 \ 2 \ 0$ pole, and p is a pole at the intersection of the zones $l \ c$ and $d \ b$, then it follows, because p is on the zone $l \ c$, its second index must be twice as great as its first, and, because p is on the zone $d \ b$, its last index must be the same as the first. It is evident that the symbol $1 \ 2 \ 1$ satisfies both conditions, hence $1 \ 2 \ 1$ is the symbol for p .

* The form of the symbol for planes on the zone under consideration is $k \ h \ 0$; or, if we divide all the indices by k , the plane has the symbol $\frac{h}{k} \ 1 \ 0$, so that we have the last two indices always alike, thus expressing a constant ratio.

While it is an advantage for the non-mathematical student to determine the indices of a pole at the junction of two zones by first principles as given above, it seems desirable here to point out an easy general method of solving the problem, the mathematical proof for which will be found in special treatises.

Zone Symbol or Index.—Having given two poles in a zone, we obtain the zone symbol by treating the indices of the two poles as described on page 33. Thus with the zone $c m_1$ of figure 29 we have the two poles $m_1 = 110$, and $c = 001$. Then

$$\begin{array}{ccccccc} m & 1 & 1 & 0 & 1 & 1 & 0 \\ & & \swarrow & \searrow & \swarrow & \searrow & \\ c & 0 & 0 & 1 & 0 & 0 & 1 \end{array}$$

and zone symbol

$$\begin{aligned} &= (1 \times 1 - 0 \times 0), (0 \times 0 - 1 \times 1), (1 \times 0 - 1 \times 0) \\ &= 1 \bar{1} 0 \dots\dots A \end{aligned}$$

similarly the zone symbol for the zone $d b$ ($d = 101$, $b = 010$) is found to be

$$= \bar{1} 0 1 \dots\dots B$$

Now treat these zone symbols in the same way as the pole indices have been treated, thus

$$\begin{array}{ccccccc} A & \dots\dots & 1 & \bar{1} & 0 & 1 & \bar{1} & 0 \\ & & & \swarrow & \searrow & \swarrow & \searrow & \\ B & \dots\dots & \bar{1} & 0 & 1 & \bar{1} & 0 & 1 \end{array}$$

and we have $\bar{1} \bar{1} \bar{1}$, or 111 , and this is the required symbol for the pole o , as the student already knows, at the intersection of the zones $m c$ and $d b$.

Similarly treating the pole indices l and c , and the pole indices b and d , we obtain the symbol of p as 121 .

Meaning of the 111 Pole in Different Systems.—

In the illustrations of spherical projection so far the regular system alone has been referred to, in which the parameters are all the same length. It should be mentioned, however, that the parameters have different lengths in all systems but the hexagonal and cubic, while in the tetragonal

system two of the parameters are equal and the third different. Hence, while the 111 pole in all the systems refers to a plane which cuts the extremities of the parameters, the actual lengths of the axes cut off may be different, according to the way in which the parameters a, b, c vary. In a spherical projection the lengths of the parameters are not indicated as they are in a drawing, but the position of the 110 pole on the projection gives the relation of $a : b$, while the position of the 011 pole shows the relation of $b : c$.

Form.—The term *form* has been used in these lessons, but at present no precise meaning of the term has been given to it. With the help of a map of the planes of symmetry we can now easily understand the definition, which is as follows :—

"The figure consisting of a given face, and the faces which by the law of symmetry of the system of crystallization are required to co-exist with it, is called a *form*. The form consisting of the face hkl and its co-existent faces may be denoted by the symbol $\{hkl\}$. When, however, there is no danger of mistaking the form for a zone or a face, having the same indices, the braces may be omitted."—

"Tract on Crystallography," by W. H. Miller, 1863, p. 19. Figure 30 is a map of the sphere containing the planes

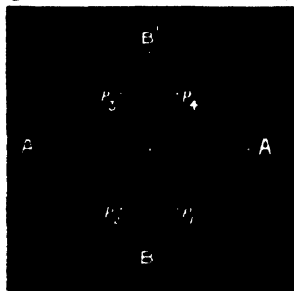


Fig. 30.

of symmetry of the prismatic system (three planes at right angles to each other). Put any pole p_1 on the sphere, but not in one of the planes of symmetry, then p_1 is reflected by the plane $B B'$ to p_2 , and the two poles p_1, p_2 are both reflected by the plane $A A'$, giving

us the poles p_3 and p_4 . The plane of the paper reflects these four poles to the upper part of the sphere, and to indicate this reflection small circles may be drawn around the dots as in figure 31; and as no further reflection is

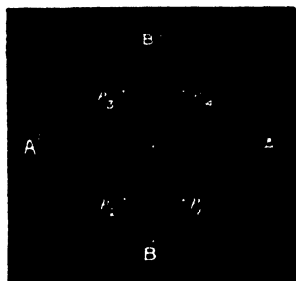


Fig. 31.

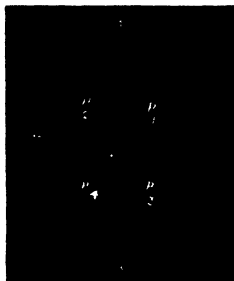


Fig. 32.

possible, we have in figure 31 a complete map of all the faces of the form $\{p\}$. If p_1 is the parametral plane, that is, cuts the parameters $a b c$ at unit length, the form $\{p\}$ is the form 111 , and consists of eight planes, $p_1, p_2, p_3, p_4, \bar{p}_1, \bar{p}_2, \bar{p}_3, \bar{p}_4$. The geometrical figure corresponding to the map is that of figure 32, in which there are eight faces, each face corresponding to one of the dots or circles of figure 31. The model Plate IV., figure 1, is a model of a similar form, but the faces are lettered z instead of p .

Now suppose p_1 (figure 33) to be on the horizontal

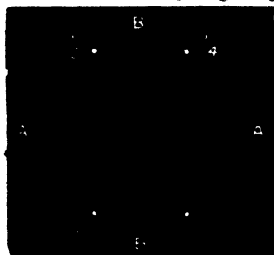


Fig. 33.

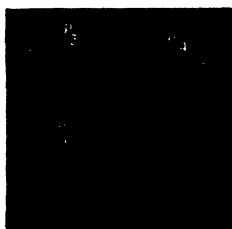


Fig. 34.

plane of symmetry (the plane of the paper), p_1 is reflected by the plane $B B'$ to p_2 , and the two poles p_1, p_2 are bodily reflected to p_3, p_4 , but no further reflection is possible. Suppose p_1 to be the 1 2 0 pole, then figure 33 may be taken as a map of the form $\{1\ 2\ 0\}$. It will be noticed that there are only four poles in the form, and the geometrical figure corresponding to the map is an *open* prism of four sides (figure 34). Since the figure does not enclose a space, such a form is said to be *open*. The model Plate IV., figure 11, is a model of this form, but in addition there is on the model the basal planes $0\ 0\ 1$ and $0\ 0\ \bar{1}$.

Now let p_1 be at the intersection of two of the planes of symmetry, as in figure 35.

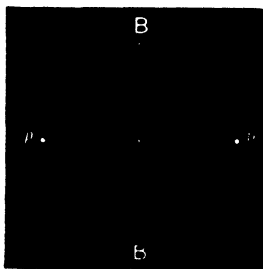


Fig. 35.

No reflection is possible except by the plane $B B'$, which produces the plane $\bar{p}_1$, but if there were no *plane* of symmetry, but only *centro*-symmetry, the pole $\bar{p}_1$ would be in the position marked all the same. Hence a pole p at the junction of two planes of symmetry in the prismatic system will have merely its opposite pole, and the form consists of one plane only.

In the model of nickel sulphate the plane c is a form of this kind, but as the plane must have some thickness, there will of course be a repetition of the plane c at $\bar{c}$ on the opposite side of the crystal, and in this light the form might be spoken of as made up of two planes. In the model Plate IV., figure 11, the basal plane is a plane at the junction of the planes of symmetry $A A'$, $B B'$, and with the opposite plane make up the form $\{0\ 0\ 1\}$.

In the model Plate IV., figure 12, are three forms of this kind, viz., the form $\{100\}$, the form $\{010\}$, and the form $\{001\}$.

In representing the poles of a form the same letter should be used, as really the form is a mere repetition of the same plane. It is convenient, however, to put undashed letters, p_1, p_2 , &c., in the positive octant, to use dashed letters, $\bar{p}_1, \bar{p}_2$, &c., for opposite poles, and to indicate poles produced by reflection by numerals, as p_2, p_3 , &c.

It will be convenient here to give figures of the spherical projection of planes of symmetry of the six systems, or rather five of them, for it will be remembered the anorthic system has no plane of symmetry.

Reference should be made to page 17 when studying the following figures :—

MONO-SYMMETRIC SYSTEM.—
One plane of symmetry, represented by the circle of projection, figure 36.

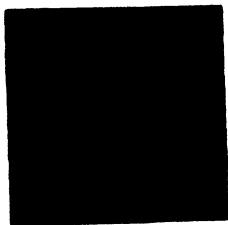


Fig. 36.

ORTHO-RHOMBIC SYSTEM.—
Three planes of symmetry at right angles to each other, figure 37.

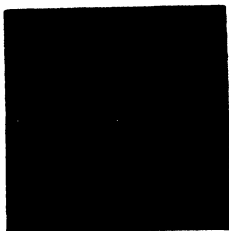


Fig. 37.

HEXAGONAL SYSTEM.—Three planes of symmetry at angles of 120° , represented by three thickened diameters of the figure, or seven planes of symmetry, represented by the three thickened diameters, the three bisecting thin diameters, and the circle of projection, figure 38.

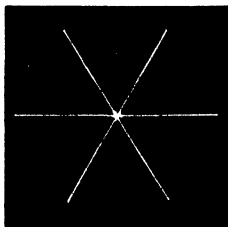


Fig. 38.

TETRAGONAL SYSTEM.—Five planes of symmetry. Four at 45° to each other, represented by the four diameters of the figure, and one at right angles to these, represented by the circle of projection, figure 39.

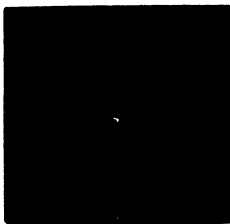


Fig. 39.

CUBIC SYSTEM.—Nine planes of symmetry, as described at pages 16 and 42, see figure 40.



Fig. 40.

In concluding this lesson, it may be pointed out that each system is capable of having a certain number of *holohedral* forms, though reference has only been made in detail to the ortho-rhombic system. For meaning of the term holohedral see Lesson IX.

In the regular system, for example, there are seven forms.

1. The general form, $h\ k\ l$, known as the hexakis octahedron. Figure 41 represents an example of this form, the form $\{1\ 2\ 3\}$. Draw the planes of symmetry of the regular system, see figure 40, mark a pole within the triangle $a\ o_1\ m_1$, and then, by symmetry, obtain the other poles, when a map of this form will be obtained. Note that there are forty-eight faces to complete this form.



Fig. 41.



Fig. 42.

2. The general form $h\ h\ k$ where h is greater than k , known as the triakis octahedron. Figure 42 is an example of this form $= \{2\ 2\ 1\}$. For the projection put a pole between m_1 and o_1 on the zone $m_1\ o_1$ (figure 40), and obtain by symmetry the remaining poles. Note that there are twenty-four faces in this form.

3. The general form $h\ k\ k$, h being greater than k , known as the 24-faced trapezohedron. Figure 43 is an example of the form $= 2\ 1\ 1$. For the projection put a pole on the plane of symmetry $a\ o_1$ between a and o_1 (figure 40), and obtain by symmetry the remaining poles. Note that there are twenty-four faces in this form.

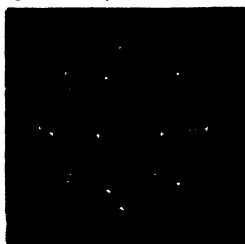


Fig. 43.



Fig. 44.

4. The general form, $h k o$, is known as the four-faced cube. Figure 44 and model Plate IIIA. illustrate an example of this form $= 2 1 0$. For the projection put a pole on the plane of symmetry $a m_1$ between a and m_1 (figure 40), and obtain by symmetry the remaining poles.



Fig. 45.

5. The general form $1 1 0$ is called the regular dodecahedron, see figure 45. For the projection put a pole at m_1 , figure 40, and obtain by symmetry the remaining poles. Note that there are twelve faces to this form.



Fig. 46.

6. The general form $1 1 1$, known as the regular octahedron, see figure 46. For the map put a pole at o_1 of figure 40, and obtain by symmetry the remaining poles. Note that there are eight faces in this form.



Fig. 47.

7. The general form 100, known as the cube, see figure 47. For the map place a pole at a (figure 40), and obtain by symmetry the remaining poles. Note that there are six faces in this form.

For the convenience of students who may wish to follow up the subject of stereographic spherical projection of crystals more fully than has hitherto been outlined, the following problems and remarks will be useful.

To draw the projection of a zone circle passing through any two poles, and afterwards to draw that particular diameter of the zone which lies in the plane of projection.

Let p, q , figure 48, be the two given poles, q being the most distant from c , the centre of the circle of projection. Join q, c ,

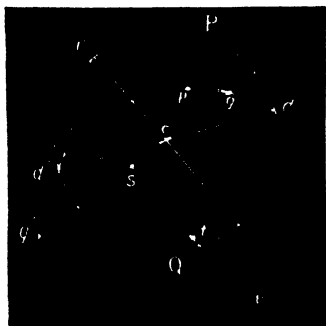


Fig. 48.

and produce this line in the direction of q' . Draw cr at right angles to qq' , join qr , and draw rq' at right angles to rq , meeting qq' at q' . Bisect qq' at s , and draw st at right angles to qq' . In the line st find a point t , such that from it a circle can be struck through

q, p, q' , cutting the circle of projection at d and d' . Then

$d q p d'$ is the projection of the required zone circle, and the line $d d'$ is the particular diameter which lies in the plane of projection.

To mark in stereographic projection any pole of a system with rectangular axes, when the indices of the pole, the system to which the pole belongs, and the relative lengths of the parameters, are given.

EXAMPLE.—Find position of the pole 1 2 3 belonging to the prismatic system, in which $a : b : c = 7.6 : 10 : 12.4$.

Draw a circle P Q, figure 49, with a radius $= c = 12.4$ parts. Draw also the planes of symmetry $a a'$, $b b'$, at



Fig. 49.

right angles to each other. Take $c x = \frac{1}{2} a = 7.6$ parts, and $c y' = \frac{1}{2} b = \frac{1}{2} c y = \frac{1}{2} (10) = 5$ parts. Join $x y'$, and draw the diameter $n c n'$ at right angles to $x y'$; draw also the diameter $z c z'$ at right angles to $n c n'$. Measure " $z c$ " in $c z$, and make " $z c = \frac{1}{2} c = \frac{1}{2} c z = \frac{1}{2} (12.4) = 6.2$ parts. Join " $z q$, and

draw the radius $c s$ at right angles to " $z q$. Join $z' s$ by a dotted line, intersecting $c n$ at t . Then t is the position of the pole 1 2 3.

The converse problem of finding the indices when the position of the pole, the system to which it belongs, and the lengths of the parameters, are given, may be easily seen from the last example. After drawing the circle of projection of radius c , and marking off the parameters a and b , a diameter $n t n'$ is drawn through the given pole t . The diameter $z c z'$ is next drawn, then the dotted line $s' s$

passing through t . The radius cs can now be drawn. From x draw xy' at right angles to cn , and from q , the point where xy' crosses cn , draw zq at right angles to cs . The lengths cx/cx , cy/cy' , cz/cz' , will be the indices, with the first index as unity.

Though attention has not been directed to the point, the student may have noticed from the lesson on spherical projection that the angle subtended by two poles on the sphere to the eye or point of projection is one-half the actual angle between the poles. Thus, in figure 21, page 45, the actual angle between the poles $m_1 m_2$ is the arc $m_1 m_2$ of the circle ab , but the angle $m_1 E m_2$ is by Euclid, Book III., xx., one-half of the angle $m_1 b' m_2$. Similarly, while the angle between $a a'$ of figure 21 is 180° , the angle $a E a'$ is 90° .

As remarked on page 41, we seldom require to make reference to the upper part of the sphere, but the principle upon which the drawing of a zone circle through two poles is based depends upon the projection of a pole lying above the plane of projection. Imagine the eye at r of figure 48, then q is the projection of the pole q on a plane passing through the centre of the sphere, and at right angles to the paper; and if we make the angle $q r q'$ 90° , the arc subtended by $q q'$ will be 180° , as stated in the last paragraph; hence, q' is the projection of *one* diameter of a circle passing through $q q'$; and, as we have now three given points in the zone passing through $q p$, viz., q , p , and q' , we can draw the zone circle $d q p d'$.

EXERCISES.

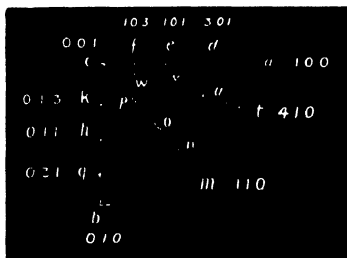


Fig. 50.

pages 55 and 56) the symbol for each of the poles u, v, w, n, o, p .

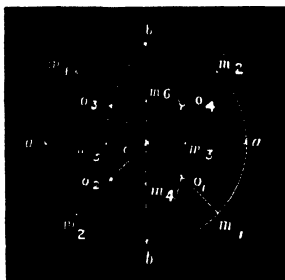


Fig. 51.

61. Figure 50 is a map of an octant of a crystal in the prismatic system, having the following poles: $a\ 100$, $b\ 010$, $c\ 001$, $m\ 110$, $t\ 410$, $d\ 301$, $e\ 101$, $f\ 103$.

There are also other poles, u, v, w, n, o, p , at the intersection of zones indicated by the map. Find by the principles explained (see

62. Figure 51 is a map of a crystal of the regular system, having the poles as indicated by letters $a=100$, $b=010$, $c=001$. The zones marked are those of the planes of symmetry. Find symbols for the planes m_1, m_3, m_4 , and o_1 .

63. Draw a map of an octant of a crystal of the regular system, as in acb of figure 51. By means of a protractor put along the zone ab , the poles k, m, n at distances such that $a\ k=18^\circ 26'$, $a\ m=45^\circ$, $a\ n=63^\circ 26'$; now, by method suggested at page 53, determine the indices of each of the poles k, m, n .

64. Draw a map of the planes of symmetry of the tetragonal system, and mark upon it the position of the poles $a=100$, $b=010$, $c=001$, $m=111$. Find also the position of the poles 210 and 120 .

65. Map the planes of symmetry of the tetragonal system, and marking a pole p anywhere on the map, find by the laws of symmetry how many faces there will be in the form. It will be well perhaps to take first what is called the *general form*, that is, when the pole is not on either of the planes of symmetry. Then put p on one of the planes of symmetry, but not at a junction. Lastly, put p at the different junctions of the planes. Make freehand sketches of the principal forms you obtain. Take now the model of nickel sulphate, or the crystal itself, and consider where the pole c would be on the map, also roughly where the poles o and t will be.

66. Two poles, $h k l$ and $m n o$, are on the zone A, while two other poles, $p q r$ and $s t u$, are on the zone B. Find the zone symbol for the zone A, and also the zone symbol for the zone B.

67. Two poles, $5 8 4$ and $6 2 1$, are on a zone A, while two poles, $5 3 2$ and $5 3 1$, are on a zone B. Find symbol for each zone. Also find indices of a pole which is at the intersection of the zones A and B.

68. In a crystal of the prismatic system the m or $1 1 0$ plane is at $64^\circ 49'$ from the pole a , and $25^\circ 11'$ from the pole b . Make a drawing showing the relative lengths of the X and Y axes, that is, relative lengths of the parameters a and b .

69. Make a stereographic projection of a barytes crystal (orthorhombic system) from the following particulars:— $a : b : c = 7.6 : 10 : 12.4$. Poles present $a = 100$, $b = 010$, $c = 001$, $m = 110$, $o = 101$, $s = 111$, $q = 114$. Compare this with the projection obtained in example 1, page 47.

69A. Taking the pole s_1 of figure 1, Plate II., as the $1 1 1$ pole, show that $a : b : c :: 7.6 : 10 : 12.4$.

LESSON VII.

Naumann's Notation. Axes and Parameters in the Six Systems.

Now that the term *form* has been explained, the method of notation, introduced by Naumann, and used by many authors, will be readily understood.

The principle of this notation is to give a symbol for the fundamental pyramid, or 1 1 1 form of Miller, and to indicate other forms by numerals or fractions in connection with the symbol.

An idea of the notation will be best obtained by an example from the prismatic system. In this system there are three axes at right angles to each other, and all of different lengths, represented in figure 3 of Plate II. There is, in Naumann's notation too, a slight difference in the symbols of the parameters, which is convenient; thus, ℓ is the vertical parameter; the longer of the two lateral parameters is indicated by $\bar{a}$, and is called the *macrodiagonal*, from the Greek *μακρός* (*makrós*), long; while the shorter of the two lateral axes is indicated by $\check{b}$, and is called the *brachydiagonal*, from *βραχύς* (*brachus*), short. See note, page 75.

Look now at figure 4 of Plate II. The double pyramid in thick lines, marked P, is the fundamental pyramid, and would, in Miller's notation, be called the form {1 1 1}. This fundamental pyramid, in Naumann's notation, is called P, the initial letter of pyramid. If a pyramid such as the {2 2 1} of Miller has twice the height of the fundamental pyramid, the symbol in Naumann's notation is 2 P; similarly the 3 3 1 of Miller would be 3 P; and when the pyramid is infinitely high, that is, when we have the form {1 1 0} of Miller, we have the symbol ∞ P (infinity P) of Naumann. If we have a pyramid half as high as the fundamental pyramid, this will be represented by $\frac{1}{2}$ P =

the $\{112\}$ of Miller; similarly $\frac{1}{2}P$ will be the $\{113\}$ of Miller; and when we come to a pyramid of no height, that is, the flat plane, parallel to the axes X and Y , then the symbol is $\circ P$ (nought P)= $\circ\circ 1$ of Miller.

In figure 4 of Plate II. is represented the fundamental pyramid, or $\{111\}$, in thick lines, the pyramid $2P$ by thin lines outside this fundamental pyramid, while the form $\frac{1}{2}P$ is represented by thin lines inside the fundamental pyramid.

Figure 5, Plate II., is a drawing of a crystal containing the forms $\circ P$, $\frac{1}{2}P$, P , $2P$, and ∞P .

Among the models there is not one from the prismatic system which illustrates this point well, but the nickel sulphate model, Plate III., figure N, will serve. The set of faces marked $\sigma_1, \sigma_2, \sigma_3, \sigma_4, \bar{\sigma}_1, \bar{\sigma}_2, \bar{\sigma}_3, \bar{\sigma}_4$, constitute the form P , while the set of faces τ_1, τ_2 , &c., constitute the form $\frac{1}{2}P$, and the two faces c and $\bar{c}$ constitute the form $\circ P$.

In the model, Plate IV., figure 11, the four prism planes make the form ∞P , while the basal planes constitute the form $\circ P$.

Let us now consider a set of forms containing planes parallel to the macrodiagonal or X axis, and which, in Millerian notation, would be represented by $\circ h k$, that is,

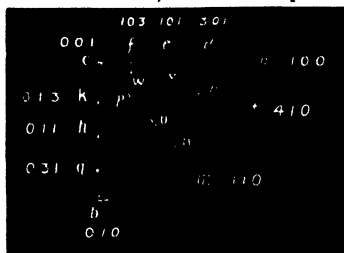


Fig. 52.

those on the zone cb of figure 52. The form h on this zone= $\{011\}$ is called $\bar{P}_\infty$, implying the form consisting of a set of planes parallel to the macrodiagonal, and cutting the brachy-

diagonal and the vertical at unit distance, represented by

thick lines in figure 7, Plate II. The planes constituting this form are called *domes* (*domus*, a house), because they resemble a roof of a house. The form $\bar{P} \infty$ is the fundamental dome, just as P was the fundamental pyramid, and the higher domes are represented as $2 \bar{P} \infty$, $3 \bar{P} \infty$, &c., while the lower domes will have the symbols $\frac{1}{2} \bar{P} \infty$, $\frac{1}{3} \bar{P} \infty$, until we come to the plane $o P$. Domes parallel to the macrodiagonal are called *macrodomes*. Similarly the set of forms having planes parallel to the brachydiagonal (*brachydomes*) will be represented by the symbols $\check{P} \infty$, $2 \check{P} \infty$, $3 \check{P} \infty$, &c.; and the low domes within the fundamental dome by the symbols $\frac{1}{2} \check{P} \infty$, $\frac{1}{3} \check{P} \infty$, $\frac{1}{4} \check{P} \infty$, &c. See figure 8, Plate II.

Special terms are often employed to represent the planes $1 \circ \circ$, $\circ 1 \circ$, and $\circ \circ 1$, that is, planes parallel to two of the axes, but cutting the third. These planes are called *pinakoids*, from the Greek *πίναξ*, a "slab." The plane parallel to the two diagonals is called the basal pinakoid, that parallel to the macrodiagonal and the vertical axis is called the macropinakoid, that parallel to the brachydiagonal and vertical axis is called the brachypinakoid.* These have, in Naumann's notation, the symbol $o P$ for the $\circ \circ 1$ plane, $\infty \check{P} \infty$ for the plane parallel to the brachydiagonal, and $\infty \bar{P} \infty$ for the plane parallel to the macrodiagonal.

The model, Plate IV., figure 12, is instructive as to the meaning of these terms.

There is now only the case to be considered when the form is general, that is, cuts the three axes. This general form, as expressed by Miller, is $h k l$; as expressed by Naumann, it is either $m \check{P} n$, or $m \bar{P} n$, where m and n are fractions or integers referring to portions or multiples of the parameters cut off. It must be remembered, however, that

Other names are $1 \circ \circ = \text{proto-pinakoid}$; $\circ 1 \circ = \text{deutero-pinakoid}$; $\circ \circ 1 = \text{trito-pinakoid}$. Again, $o k l$ is called the *proto-dome*, and $h o l$ the *deutero-dome*.

the first symbol, m , refers to $\bar{c}$, or the vertical axis; the middle symbol, $\check{P}$ or $\bar{P}$, refers to the shorter or longer axis, as the case may be, the symbol n indicating how many parts of this parameter are taken. The remaining parameter, $\bar{a}$ or $\bar{b}$, as the case may be, is implied as unity.

For example, if, following Miller, we make $\bar{a}$ the longer and $\bar{b}$ the shorter of the two parameters forming the diagonals, then, in Millerian notation, the plane 1 2 3 means a plane which cuts at

$$\frac{1}{3} \text{ of } \bar{a} \quad \frac{1}{3} \text{ of } \bar{b} \quad \frac{1}{3} \text{ of } \bar{c};$$

and this would be expressed by Naumann as

$$\frac{1}{3} \check{P} \frac{1}{3},$$

in which $\bar{a}$ is taken as unity.

If we make $\bar{b}$ unity in the plane 1 2 3, we have (see Lesson III., page 24) the new symbol as

$$2 \bar{a} \quad \bar{b} \quad \frac{2}{3} \bar{c};$$

and this, in Naumann's notation, would be

$$\frac{2}{3} \bar{P} 2.$$

Hence, the plane 1 2 3 can be expressed either as $\frac{1}{3} \check{P} \frac{1}{3}$, or $\frac{2}{3} \bar{P} 2$.

In figure 9, Plate II., the thick continuous lines represent the plane 1 2 3 as expressed by Miller, or by the symbol $\frac{1}{3} \check{P} \frac{1}{3}$ of Naumann; the thin line represents the plane $\frac{2}{3} \bar{P} 2$ of Naumann, parallel to, and hence, of course, the same plane as the other.

In the regular system the symbol O is used for the fundamental pyramid, or *octahedron* (the 1 1 1 of Miller). The symbols $2O$, $3O$, refer to octahedra of twice or three times the height of the fundamental octahedron, and are symbols of two examples of the *triakis octahedron*. As the numbers in front of the O increase, the octahedra forming the triakis octahedron get higher and higher, and when we come to ∞O we have the dodecahedron. The cube has the symbol $\infty O \infty$; the four-faced cube the symbol $\infty O \infty$; the twenty-four-faced trapezohedron the symbol

$m \ O \ m$. The general form, $h \ k \ l$, of Miller, has the form $\frac{l}{h} \ O \ \frac{l}{k}$ of Naumann. The symbol of that plane of the form, which has the last index unity, is adopted, and m and n represent the ratio of the first to the second intercept when this is the case. For example, the symbol $1 \ 2 \ 3$ of Miller means a plane

$$\frac{1}{3} a \ \frac{1}{2} b \ \frac{1}{3} c, \text{ where } a=b=c.$$

Make the last index unity, and we have

$$3a \ \frac{3}{2}b \ c.$$

Hence, Naumann's symbol is

$$3 \ O \ \frac{3}{2}.$$

Naumann's symbols in other systems may be deferred for the present.

The terms pinakoid and dome have been illustrated at length in connection with the prismatic system. These terms, however, are used in other systems, more particularly in the oblique system. Speaking generally, the forms $\{1 \ 0 \ 0\}$, $\{0 \ 1 \ 0\}$, and $\{0 \ 0 \ 1\}$ constitute the three pinakoids of a system, while the forms $\{1 \ 0 \ 1\}$ and $\{0 \ 1 \ 1\}$ constitute the fundamental domes, the form $\{1 \ 1 \ 0\}$ being retained as the fundamental prism. The three pinakoids of the oblique system are commonly termed the $\{1 \ 0 \ 0\}$ the *orthopinakoid*, the $\{0 \ 0 \ 1\}$ the *basal pinakoid*, and the $\{0 \ 1 \ 0\}$ the *clinopinakoid*.

The $\{1 \ 1 \ 0\}$ is the fundamental prism (four planes), while the $\{1 \ 0 \ 1\}$ and the $\{\bar{1} \ 0 \ 1\}$ together form the fundamental *orthodome*, and the $\{0 \ 1 \ 1\}$ the fundamental *clinodome* (four planes).

Figure 10, Plate II., is a spherical projection, while figure 10a of the same plate is a plan of the planes just referred to. The only difficulty the student will have, I think, is in reference to the orthodome. It will be noticed that this is not a single form, being made up of the two forms v and w in the projection. The form $v=v_1, \bar{v}_1$ in figure might be two rough planes, while the form $w=w_1, \bar{w}_1$ was two

smooth planes. The form v is sometimes called a half dome, the other half being the form w .

NOTE.—In the spherical projection the direction of the axes $X X'$, $Z Z'$ are indicated by dotted lines; the second axis, $Y Y'$, is at right angles to the plane of the paper, and passes through centre of projection as indicated at Y .

Position of Axes and Lengths of Parameters in the Six Systems.—The close of the present lesson gives a good opportunity for summing up what has been implied rather than emphasized, viz., the position of axes, and ratios of parameters in the six systems of page 17.

The axes of a crystal are three imaginary lines passing through the crystal, the three lines being parallel to three edges of the crystal. The parameters are three lengths measured on the axes, the lengths of these parameters determining the lie of the 111 plane. Other planes cut the parameters at other points than their extremities, the lengths cut off being called *intercepts*.

Anorthic system.—The three axes as in figure 12, page 20, are at all angles, so long as no two of them are at right angles to each other, and the parameters are all of different irrational lengths.

Mono-symmetric system.—Two of the axes lie in the plane of symmetry, and are inclined to each other; the third is at right angles to these two axes. The parameters are all different. See projection, figure 10, Plate II., referred to on page 73.

Ortho-rhombic system.—Axes all at right angles in intersections of planes of symmetry. Parameters all different.

Hexagonal system.—Three axes each in a plane of symmetry, and inclined equally to each other, but not at right angles. The axes are parallel to the edges of the primitive rhombohedron. The parameters are all equal (Miller). Some authors use Bravais' method of four axes; one, the primitive axis, being in the intersection of the

planes of symmetry; the other three (lateral axes) being in planes of symmetry at 60° from each other, and in one plane. The parameters on the lateral axes are equal; that on the primitive axis different.

Take up the model of the rhombohedron, K, Plate III., and look down upon the three faces, r_1, r_2, r_3 . The three edges $r_1 r_2, r_2 r_3, r_3 r_1$ are parallel to the axes in the Millerian method.

Now take up the model of the hexagonal prism, figure 8A, Plate IV., and look down upon the six-sided basal plane marked o . The dotted lines correspond to the lateral axes, while a line at right angles to these is the direction of the principal axis, according to the Bravais method. The notation in the hexagonal system is somewhat difficult, and hence little is said of it in this elementary work.

Tetragonal system.—Three axes at right angles to each other in intersections of planes of symmetry. Two of the parameters equal; the third different.

Cubic system.—Three axes at right angles to each other in intersections of planes of symmetry. Parameters all equal.

Note on Conventional Order in lengths of parameters.—In the projections of Miller the parameters in the ortho-rhombic system are generally arranged with a longer than b , and that is the order of magnitude used in the illustrations of Naumann's system in this lesson. Groth and other German writers usually make b longer than a , that is, make b the macrodiagonal and a the brachydiagonal. It would undoubtedly be convenient if crystallographers would adopt a uniform system in reference to magnitude of parameters.

EXERCISES.

71. Make a projection of the three axes of the prismatic system, and point out which is the vertical axis, which the macrodiagonal, and which the brachydiagonal.

72. With your projection thus formed make a free-hand drawing of the form P , $2P$, and $\frac{1}{2}P$.

73. Make a free-hand drawing of a crystal of the prismatic system, bounded by the planes ∞P and oP .

74. Make a free-hand drawing of the fundamental macrodome, also of a dome twice as high, and of one-half as high. Give symbols for each form.

75. Draw similarly the fundamental brachydome and domes twice and one-half as high as the fundamental.

76. What do you understand a pinakoid to be? On the drawing of the crystal, figure 1a, Plate II., point out which plane you regard as the basal pinakoid, which the macropinakoid, and which the brachypinakoid; also which you take to be the macrodome, and which the brachydome. Give symbols for each plane in Naumann's notation, and also give probable symbols for the forms m and z of the drawing. In judging which is the macrodome and which the brachydome, consult the spherical projection of the crystal, figure 1 of same plate.

77. The following are symbols of some forms in the prismatic system according to Miller :—

1 1 1	0 1 0	1 0 1
1 1 0	1 0 0	2 3 4
0 0 1	0 1 1	3 3 2

Taking the first index as referring to the macrodiagonal, the second to the brachydiagonal, and the third to the vertical axis, give Naumann's symbol for each form.

78. Translate the following symbols into Millerian symbols :—

∞P	$\infty \bar{P} \infty$	$2 \bar{P} 3$	$\check{P} \infty$
oP	$\infty \check{P} \infty$	$\bar{P} \infty$	$3 \check{P} 2$

79. Find either on the model of gypsum, or on the crystal itself, the planes constituting the clinopinakoid, and those constituting the fundamental prism.

LESSON VIII.

Physical Properties of Crystals of the different systems.

UNDER the head of physical properties of minerals may be put—

Hardness	Behaviour in relation to
Structure	i. Light
Cleavage	Transparency
Fracture	Lustre
Specific gravity	Colour
Streak	Phosphorescence
Smell	Refraction phenomena
Taste	
	ii. Heat
	iii. Electricity
	iv. Magnetism

Of these properties many have no special reference to systems of crystallization, and belong rather to mineralogy than crystallography.

As connected with symmetry, reference may be made to hardness, cleavage, and behaviour in relation to light, heat, and electricity.

The peculiar properties of crystals in reference to hardness, structure, cleavage, light, heat, and electricity, are symmetrically situated in reference to the planes of symmetry, and are constant in the same direction. Hence, some authors will define a crystal without reference to the geometrical form that the body takes up when free to crystallize.

We may, for example, have a mass of calcite without any definite form, but, on breaking it, we soon find that it cleaves symmetrically in reference to three planes at 120° ; its action on light is the same in directions equally inclined to the planes of symmetry, and its other physical properties are grouped about these planes. We can well imagine that these effects are brought about by the systematic arrangement of molecules; hence a crystal has been defined as "a system of molecules belonging to an individual substance symmetrically arranged and presenting the same properties along all lines taken parallel to the same direction or to directions that are similarly disposed in respect to symmetrically repeated features" (Maskelyne).

Again, Groth, *Physikalische Crystallographie*, 1885, p. 7, says, after pointing out that physical properties generally depend upon elasticity, "a crystal is best defined as a solid body, the elasticity of which is equal in all parallel directions, but, on the contrary, in different directions is different."

Take up a crystal of gypsum (No. 2 in the box of specimens). Note that if you draw the thumb-nail over the cleavage face ($=b$ of the cardboard model, Plate III. L), the specimen is scratched easily; but trying either of the faces l or m , these are more difficult to scratch. This shows clearly a difference in structure in different directions of the crystal. Note, too, what has been established generally, that crystals are softest on the cleavage planes.

Try the nail on other specimens in the box, and you will fail to scratch them. It is convenient in describing minerals to specify their hardness, and this is generally given in what is known as Mohs' scale, in which ten typical minerals are numbered from 1 to 10. It may assist the memory to put the names of these typical minerals as though the minerals themselves were placed in a box with

ten divisions, according to the following scheme :—

1 Talc.	2 Rock Salt, or Gypsum	3 Calcite.	4 Fluor spar.	5 Apatite.
6 Orthoclase Felspar.	7 Quartz.	8 Topaz.	9 Corundum	10 Diamond.

Thus, if a mineral, barytes, for example, is found to scratch calcite, but not to scratch fluor spar, it would be described as having a hardness of from 3 to 4. Hardness is generally expressed by the symbol H . Thus, $H=3$ refers to a mineral whose hardness is the same as calcite.

By means of the sclerometer, an instrument consisting of a steel or diamond point, weighted until a scratch is produced, the hardness of a mineral in different directions on a certain face can be estimated. To do this the weighted point is drawn a given number of times over the face in parallel lines, the dust collected and weighed. The direction is then changed, and the dust collected in this second scratching, and so on in several directions; that direction in which the least powder is collected being the hardest.

By this method it is found that hardness, as above defined, on a face is symmetrical, and related to cleavage. Thus

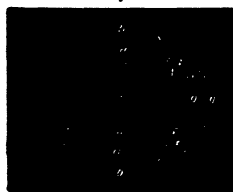


Fig. 53.

with barytes, drawing radial lines on the face & the length of the radius corresponding to hardness in the direction of the radius, the ends of the radii, trace a star represented in figure 53. It will be noticed that the hardness as

tested in this way is least in the direction of the cleavage planes m, m , and greatest in lines bisecting these directions.

The curve obtained by measurements with the sclerometer is called the *curve of hardness*. The curve is related to cleavage in the crystal, as shown very prettily by a comparison of figures 54 and 55, which represent the curves

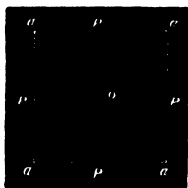


Fig. 54.

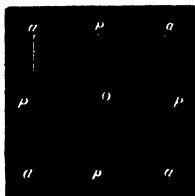


Fig. 55.

of rock salt and of fluor spar, as traced on the cubic faces. It will be noticed that the curve on the rock salt, figure 54, has its minimum breadth parallel to the cubic face, while that of fluor spar, figure 55, has its minimum breadth parallel to an octahedral face. These curves show then that the hardness *on a face* is least in the direction of cleavage, although, as has already been stated, the mean hardness of cleavage faces is generally less than that of other faces.

Cleavage.—Take up a crystal of calcite (No. 4 in the box supplied with this work), and you will note that there are many faces present termed *natural faces*, but probably one face presents itself which has the appearance of being produced by a fracture of the crystal. If such a face is not there, one or more may easily be produced by striking the crystal with a hammer near one edge, and not unlikely the *cleaved faces* forming the rhombohedron will be obtained. Along with the crystal a cleaved specimen from the spoil heap of a mine will be found. This cleavage form has been obtained by the successive blows and rough treatment at a mine in separating the ore from the gangue. Again look at

your crystal, and see if you can observe indications of cracks in the substance of the crystal itself; these are commonly present, and their direction is parallel to planes of cleavage. Figure 56 is a drawing of one of the crystals of calcite supplied with this work (No. 4 in the box); r is a cleaved face, the others are natural faces. The crack at $c c c$, it will be noted, indicates a plane parallel to the cleavage plane r .

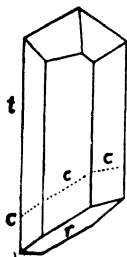


Fig. 56.

Take a crystal of fluor spar, No. 6 in the box, hold it up to the light, and see if any cracks present themselves; they are not usually present.

The planes of cleavage are however easily produced by striking the crystal with a hammer, as though to knock

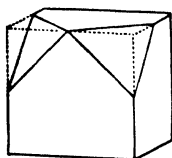


Fig. 57.

a corner off, and, with a little skill, if you care to sacrifice your crystal, you may from the cubic crystal obtain an octahedron. See figure 57, in which is represented a cube with two of its corners knocked off in the way suggested.

Similarly examine other crystals. Barytes often shows cracks indicating cleavages parallel to the face $o o r$, and to the faces of the form $\{110\}$. The specimen of nickel sulphate in the box you will find is easily cleaved parallel to the face c ($o o r$), while gypsum is cleaved parallel to the $o r o$ face most easily, as has already been pointed out. Having obtained slices of gypsum, and of nickel sulphate, reserve them for the polarization experiments, to be described presently.

Relation to Light.—Colour.—Minerals when crystallized have a variety of colours, and even in the same species the colour may be various. The specimens of fluor spar provided in the box accompanying this work are either a beautiful green or purple. But this mineral is met

with in a variety of other tints, and even colourless. The specimen of calcite is colourless ; but this mineral also occurs of a brown, pink, and purple colour. In the case of salts crystallized from their solutions the colour is constant ; thus the copper sulphate crystal, and the crystal of nickel sulphate, have, as far as I know, the one only a blue and the other only a green colour.

The colour of fluor spar is not permanent, for, when heated (see next experiment), the colour disappears ; the same is true of yellow topaz, and even amethyst.

Associated metals often give characteristic colours. Thus, manganese gives a violet colour to calcite. Blende free from iron is colourless ; but when iron is present it produces in the mineral a brown or black colour. The violet colour of amethyst is said to be due to ferric acid.

Phosphorescence.—Many minerals, and indeed many substances, when exposed to a bright light, and then carried into a dark room, give out light ; the phenomenon generally lasts for so short a time that a special instrument (the phosphoroscope) is required in order to observe it. The diamond, ruby, and fluor spar are perhaps the most marked phosphorescent minerals. The phosphorescence of fluor spar when *heated* is easily observed.

Phosphorescence is well seen in the so-called luminous paint, which consists of sulphides of the metals of the alkaline earths. What has been called Hell Fire Stone is a calcium carbonate. This stone when rubbed or scratched gives out a red line of light. It derives its name from the miners, who were astonished to find at a great depth in the earth a stone giving out fire when struck with their picks.

EXPERIMENT.—Place one or two fragments of the fluor spar broken off in trying its cleavage, or the fragments supplied in the box, into a small test tube, and heat the tube over a Bunsen burner, or over the chimney of a burning paraffin lamp. The fragments soon give out an

extremely beautiful violet or greenish light, which can of course be seen best when the room is dark. Note that during the heating the colour of the fluor spar is destroyed.

Fluorescence.—Hold a crystal of fluor spar in the sunlight, or expose it to the light of burning magnesium, and note the beautiful bloom which appears on the crystal. This bloom is due to the property which many substances have of altering the character of light incident upon them. Such substances are termed *fluorescent*, and of these fluor spar is a marked example. Those who have taken quinine will have noticed a bloom in the solution when exposed to sunlight. The various paraffin oils used for illumination show also this property in a noticeable degree.

The fluorescence is most marked when the fluorescent substance is viewed at right angles to the direction of the incident light. Thus, if the sunlight is streaming horizontally from west to east, the fluorescent crystal must be viewed from the north or south, or in a vertical plane passing through these points.

Lustre.—When light falls upon a body, the portion of light reflected enables us to see the body, and the condition of the surface causes the peculiar appearance termed *lustre*. Now, as already stated, since the material of a crystal has different properties in different directions, we should expect the lustre to be different on different faces of a crystal. Among the crystals in the box note, for example, with fluor spar, that the lustre of all the faces is glass-like, or *vitreous*. With gypsum the face *b* (cleavage plane) is *pearly*, while the faces *l* are vitreous, and the faces *m* are *dull* to vitreous. With the crystal of barytes, and also of calcite, the lustre generally will be recognised as vitreous, though, as already remarked, see page 14, the plane *c* of barytes has a pearly characteristic appearance.* Other terms used in expressing

* Two kinds of barytes crystals are supplied in the boxes. The above description refers to one of the specimens. The other specimen corresponds to the model 8 of Plate IV. The faces *n* are dull, while the faces *m* are bright and vitreous. Only one of the crystals will be found in each box.

lustre are *metallic* (galena, iron pyrites), *adamantine* (diamond, blende), *resinous* (idocrase, colophonite), *silky* (crocidolite), *waxy* (wax opal).

The student who can visit the British Museum of Natural History should study the educational collection of minerals in the window-cases II., III., and IV. of the mineral gallery. He will find there typical specimens illustrating physical characters of minerals. See also for further information "An Introduction to the Study of Minerals, with a Guide to the Mineral Gallery," by L. Fletcher, printed by order of the trustees of the British Museum; price sixpence.

Polarization phenomena.—To study the effect of crystals on polarized light requires a special instrument termed a polariscope. Microscopes are often fitted with a polarizing arrangement, and special instruments, unfortunately of an expensive character, are supplied by dealers in philosophical apparatus. Unless the student has access to a polariscope, he is advised to make for himself the following apparatus, which will at any rate show some of the phenomena very clearly.

To Make a Cheap Polariscope.—Obtain from a glazier, or from a glass warehouse, three pieces of "patent plate" glass, or best window-glass, about one-sixteenth of an inch thick, or rather more. Two of these pieces should be four inches by seven inches, the other four inches square. A piece of silvered glass (looking glass), four inches square, will also be wanted. These materials will cost from sixpence to one shilling.

Now get from a carpenter two pieces of deal, one piece six inches by $3\frac{7}{8}$ inches and one inch thick, the other $4\frac{1}{2}$ inches by $3\frac{7}{8}$ inches and half an inch thick; also four strips, each fifteen inches long, three-quarter inch wide, and half an inch thick.

Mark off on each of the strips on the broad side, and in the central line indicated at A and B, in figure 58, two

points, as a guide for the insertion of nails or screws when

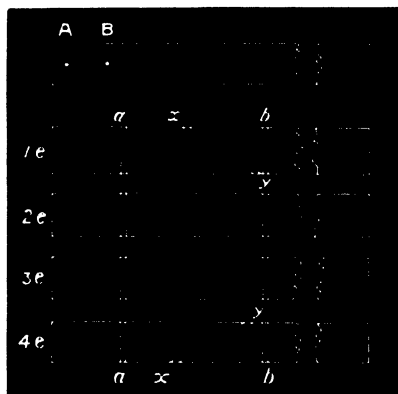


Fig. 58.

fitting the apparatus together. A at half an inch, and B at $2\frac{1}{2}$ inches from one end.

The side of the strip on which are the points A B may conveniently be called the outside.

Turn the laths completely over, and make saw cuts or grooves about one-eighth inch wide, and one-eighth inch deep, in the positions shown in figure on the insides of the strips; *a* at three inches, *b* at nine inches from the end *e*. Make also grooves *x y* on two of the laths, the angle *b y x* being 57° . If the distance *b x* is $1\frac{1}{8}$ inch, this will give about the required angle.

Having prepared the laths as just described, fit the frame together by screws, as indicated in figure C. Plate II.; the laths 1 and 4 being placed with their inside faces opposite to each other, the laths 2 and 3 also opposite. When the frame is thus fitted, slide the looking glass in the grooves *a a*. One of the pieces of glass, seven inches by four inches, slide in the grooves *x y*, as shown at P of figure C.

Slide the four inch square glass in the grooves *b b*, to form a table T, and place the remaining piece of glass so that one end rests on the table against the uprights 4 and 2, the other end being against the uprights 1 and 3, as shown at A in figure C, Plate II. The glass will then slope at about the required angle of 57° .

The plain glass P is called the polarizer, while the piece A is called the analyser. It is an advantage to paint with black colour the back of the glass forming the analyser.

To use the instrument place it on a table near a window, so as to let the light of the sky fall upon the mirror P (polarizer) somewhat in the direction of the dotted line Q P, and then look into the mirror A (analyser) from between the supports 1, 3. Nothing special will be observed. But now place on to the stage, or table T, the film of mica supplied in the box of specimens, when, on tilting the film at various angles, a brilliant series of colours will be observed, or the mica may be placed on the silvered glass S, when the same phenomena will be observed.

Introduce on to the stage T of the polariscope a piece of glass, when no difference will be observed, as is obvious, since glass itself is used as the material of the stage. If a slice of fluor spar, or of any transparent crystal of the regular system, be introduced on to the stage, its behaviour is the same as glass, that is, no change will be observed. But, with your penknife, cleave a very thin slice of gypsum, No. 2 in the box of specimens, and place it on the stage, when it will be noticed that looking into the analyser the slice is beautifully coloured, the various tints corresponding to different thicknesses of the slice. It will be found, too, that on turning the slice of gypsum round in its own plane, that there will be two positions in which all colour disappears, and two positions in which the colours are most brilliant.

Place on the table of the polariscope a pair of spectacles. If these are of glass no effect will be noticed, but if they are "pebbles" most likely a beautiful series of coloured rings will be seen when the plane of the pebble is slightly inclined.

Put a piece of Russian glue on the table, when dark and light spaces will be noticed, and sometimes curves of colour. Not unfrequently a dark cross will be noticed, the arms of the cross being parallel to the lines on the glue, which mark the position of the strings which supported the glue when drying.

The squares of "concentrated jelly for table use," sold by grocers, illustrate the effect of strain and stress.

Take a cake of lemon jelly, place it on the stage of the polariscope, when no change is noticed; the jelly in fact being homogeneous behaves on the light just as glass would do. But now, while the cake is horizontal, press the sides with the thumb and finger, when the part pressed immediately becomes bright, and probably a series of curves of colour are produced. The jelly as sold is often somewhat dull on the surface, so it is better to cut clean surfaces, which can easily be done with a dinner knife.

Without entering into details, the general conclusion to be drawn from the experiments is that when a medium is homogeneous it has no action on polarized light, but if the medium is under stress or strain, and thus has different elasticities in different directions, then it will affect the light.

The home-made polariscope is scarcely sufficient to do more than enable the student who has not access to instruments to get some idea of the phenomena of polarized light. It may be useful perhaps to make a summary of the properties of crystals in relation to polarized light, though, until the student has had more experience, and extended his reading, he will perhaps not clearly understand the statements made.

Crystals of the cubic system, no matter at what incidence the light may fall, behave in all respects as a piece of glass, or jelly, or other *isotropic* medium.

Crystals of the tetragonal and hexagonal systems behave to light as a piece of glass only when the rays are at perpendicular incidence to the 001 face of the tetragonal and the 111 face of the hexagonal. Thus, with nickel sulphate (see model, Plate III. N), light *perpendicular* to the face c passes through the crystal just as though it were made of green glass. Again, with calcite, if we grind and polish a face at right angles to the edge t of the prism (see figure 56), we have a face corresponding to the 111 plane, and light *perpendicular* to this plane passes through the crystal just as though it were of glass. I have italicised the word perpendicular lest the student might imagine that if light fall at an oblique incidence on the face 001 of the tetragonal, or the 111 face of the rhombohedral system, that in this case also the crystals would behave as glass.

Optic axis.—A crystal which behaves like glass in *one direction only* is termed uniaxial, and this particular direction is termed the optic axis. A crystal which behaves like glass in two directions only is termed a biaxial crystal; these two directions being those of the two optic axes of the crystal. In the direction of the optic axis there is no *double refraction*; in other directions double refraction takes place, and is the cause of the coloured phenomena observed when slices of crystals are placed on the stage of the polariscope.

The model of the hexagonal prism, Plate IV., 8A, will be convenient here. Taking this model to represent any hexagonal crystal, then rays of light perpendicular to the face o pass through unchanged; in all other directions the light is doubly refracted. Hence, a direction perpendicular to o anywhere within the crystal is the optic axis.

In relation to polarization-phenomena crystals may be classified thus :—

- | | | |
|--|-------|--|
| 1. Showing no double refraction in any direction. | | { Cubic System. |
| 2. Showing no double refraction in one direction only (see page 88), uniaxial. | | { Tetragonal System.
Hexagonal System. |
| 3. Showing no double refraction in two directions (see page 88), biaxial. | | { Ortho-rhombic System.
Mono-symmetric System
Anorthic System. |

Heat and Crystalline Systems.—(i.) *Radiation.*—Crystals behave in relation to radiant heat much as they do to light, the heat rays being singly or doubly refracted according to direction.

(ii.) *Conduction.*—Crystals of the regular system conduct heat equally in all directions. Those of the tetragonal and hexagonal systems conduct heat in the direction of the optic axis at one rate, and in a plane at right angles to the optic axis at another rate. The crystals of the prismatic system conduct heat differently in the three directions of the three axes. In crystals of the oblique system the axes of conductivity are at right angles to each other, one is perpendicular to the 010 face, the others have various orientations in the plane of symmetry. In the anorthic system the axes of conductivity are various.

EXPERIMENT.—Take the gypsum crystal (No. 2 in the box), or a thick slice of it, warm the 010 face (cleavage face), and rub over the warmed face a piece of paraffin wax until the wax is melted evenly over the surface. Let this

cool. When cold, take a red hot skewer, or the iron rod provided with the box of specimens, and press the point of the skewer against the face, as shown at figure 59, when the wax will melt; but it will be noticed that the melted wax forms an ellipse, as represented at $a b c d$ of the figure. This shows that heat travels faster in the direction $a b$ than in the direction $c d$ (Senarmont's

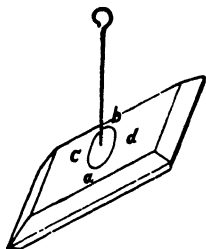


Fig. 59.

experiment).

(iii.) *Expansion*.—When glass or any other isotropic substance is heated, it expands equally in all directions. Fluor spar and other crystals of the regular system behave in this respect like glass. With crystals of the other systems, however, expansion takes place at a different rate in different directions. Thus, when a prism of calcite is warmed it lengthens in the direction of the optic axis, and actually contracts in a direction at right angles to this. It is interesting to note that though the angles of a crystal which shows unequal expansion are not equal at different temperatures, yet the law of rationality of indices (page 23) still holds.

Relation to Electricity.—Certain hemihedral and hemimorphic crystals show electric properties during the time that they change from one temperature to another. Tourmaline has long been known to exhibit this property. During a rise of temperature one end of the crystal becomes positively and the other negatively electrified. That end which becomes positive during the heating is called the *analogous pole*, the opposite pole (that which becomes negative on heating) is called the *antilogous pole*.

Relation to Magnetism.—A few minerals, of which magnetite is the most marked example, can become, like

steel, permanent magnets, showing attraction and repulsion. Magnetite, or loadstone, may have very powerful magnetic properties. It may be of interest to mention that at the New Museum, Oxford, the student may see a very fine example of a natural magnet or loadstone.

A very remarkable relation between light and electricity was predicted by Clerk Maxwell, and his keen perception has since been confirmed. So far as we are concerned, it may be noticed that Maxwell considered that those bodies which conduct electricity freely were of necessity opaque, as, for example, with the metals which are the best conductors of electricity, and at the same time the most opaque of bodies. Now, crystals will transmit light more freely in some directions than others, and, in confirmation of Maxwell's views, we find that the direction in which crystals absorb light most freely is the direction in which they conduct electricity most freely. Tourmaline, which absorbs light freely when it is propagated in a direction at right angles to the optic axis, also conducts electricity more freely in this direction, is a marked example.

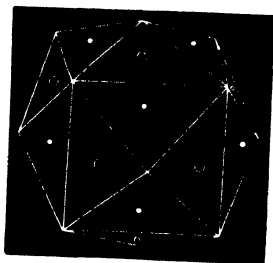


Fig. 60.

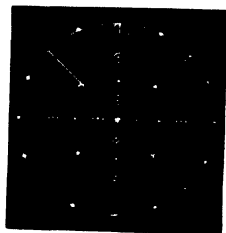


Fig. 61.

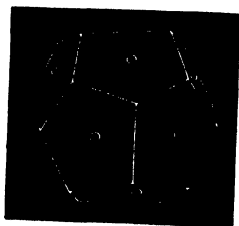


Fig. 62.

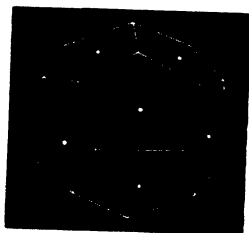


Fig. 63.

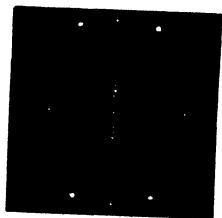


Fig. 64.

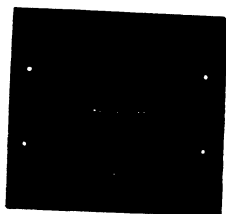


Fig. 65.

LESSON IX.

Mero-symmetry. Hemihedrism. Hemimorphism.

FROM the preceding lessons it might be supposed that the only crystalline forms to be met with are those which can be placed under one or other of the six systems referred to in Lesson II., page 17. There are, however, a multitude of crystals which, when their angles are measured, and a spherical projection made of the poles, cannot at first sight be classed in these systems. When we examine the matter more carefully, we find that striking out one or more of the planes of symmetry, and in some cases suppressing opposite planes or poles, that is, abolishing centro-symmetry, we can explain the discrepancy perfectly. Take in your hands the two models, Plate III., figure A, and Plate III., figure B. The first is a model of the four-faced cube, the second is a model of the pentagonal dodecahedron $\pi \{120\}$. Place them so that the faces e_1 and e_8 in each model correspond in position, and look at the two models, holding them so that the face e_{11} of each model is vertical, but a little lower than the level of the eye, and to the left of the point of sight, when, with a slight turning to the right or left, you will see that they correspond to the figures 60 and 62 respectively, the triangular face of the four-faced cube in the upper part of figure 60, marked with a circle, being e_1 , while the pentagon of the pentagonal dodecahedron in the upper part of figure 62 is also e_1 , and it is easy to see that the form of figure 62 is derived from figure 60 by leaving out the alternate faces, marked with dots, while a corresponding form, figure 63, is derived also from figure 60 by leaving out the alternate faces marked with circles. Make too a spherical projection of each of the forms of figures 62 and 63, as shown in figures 64 and 65, and it will be observed that each projection has three

planes of symmetry at right angles to each other. Still this is not a form of the prismatic system, for, as will be remembered from Lesson VI., page 58, the "full" form of the prismatic system has only eight identical faces, whereas this has twelve identical faces.

A form B, obtained by striking out alternate faces from a full form A, is termed a hemihedral form of A; the form A itself being called a holohedral form. In this class of hemihedral form, of which the pentagonal dodecahedron is a type, each face has an opposite or parallel face, and is styled a hemihedral form with parallel faces, and expressed symbolically as $\pi\{h\ k\ l\}^*$. The full form being $\{h\ k\ l\}$.

Take now the model of the octahedron, Plate III. D, and also the two models of the tetrahedron, Plate IV., 3 and 4, and compare them. As with the four-faced cube, and the pentagonal dodecahedron, so here with the octahedron and tetrahedron we have a holohedral and hemihedral form. The tetrahedron being derived from the octahedron by the suppression of half of its faces, taken alternately, see figures 68 and 69, and spherical projection, figures 70 and 71. In the model of the octahedron we have the faces $\sigma_1, \sigma_2, \sigma_3, \sigma_4, \bar{\sigma}_1, \bar{\sigma}_2, \bar{\sigma}_3, \bar{\sigma}_4$, while in one of the tetrahedra $\{\kappa\ 1\ 1\ 1\}$, figure 68, we have the faces $\sigma_1, \sigma_3, \bar{\sigma}_2, \bar{\sigma}_4$, while in the other $\kappa\{\bar{1}\ \bar{1}\ \bar{1}\}$, figure 69, we have the faces $\bar{\sigma}_1, \bar{\sigma}_3, \sigma_2, \sigma_4$. The hemihedral form, as exemplified in the tetrahedron, is, however, of a distinct kind from the one previously considered, inasmuch as the faces have no opposites. We have generally considered that a face must of necessity have a face parallel to it—small it may be, still that it must be there. We see, however, that in the form now under discussion this is not the case.

* The Greek letter π (Pi) is the initial of the Greek π parallel, while the Greek letter κ (kappa), referred to later on, is the initial of the Greek word *κλίμα*, from which the word *incline* may be traced.

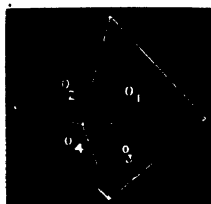


Fig. 66.



Fig. 67.

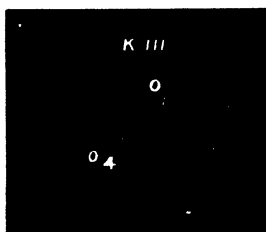


Fig. 68.

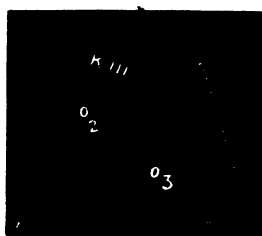


Fig. 69.

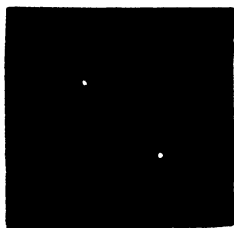


Fig. 70.



Fig. 71.

Suppose we have two tetrahedra, as indeed we have with boracite, the physical properties of the faces of each tetrahedron being different—one rough, the other bright, for example. Then, though we may combine these to produce the octahedron so far as shape is concerned, yet the crystal obtained will really be made up of two forms, and not one, as it would be if we had the octahedron simply. Thus we can imagine, and indeed we might have, an octahedron of boracite corresponding in form to the model of the octahedron or to figure 66, but in which the faces $\sigma_1, \sigma_3, \bar{\sigma}_2, \bar{\sigma}_4$ are bright, while the faces $\bar{\sigma}_1, \bar{\sigma}_3, \sigma_2, \sigma_4$ are dull.

The tetrahedron is an example of *hemihedrism with inclined faces*, represented in symbols by $\kappa \{111\}$ and $\kappa \{\bar{1}\bar{1}\bar{1}\}$, the two forms positive and negative being indicated by positive and negative indices.

The chemical student will be interested in the two tetrahedra (Plate IV., 3 and 4), which are marked to illustrate van't Hoff's hypothesis as to the nature of the asymmetric carbon atom. The tetrahedron $\kappa \{111\}$ and the tetrahedron $\kappa \{\bar{1}\bar{1}\bar{1}\}$, it will be noticed, have each crystallographically one plane of symmetry, but if we consider each of the four solid angles to be points of attachment, and consider these points of attachment to be of the same character in each tetrahedron, but differently placed, as shown by the dots, triangles, circles, and crosses at the four corners of the model, then as regards these points of attachment there is no symmetry, and we have the idea of the asymmetric carbon atom. It will be noticed that we cannot by any movement make the triangles, crosses, and dots occupy the same position in space in the one model as in the other. For the advantage of this hypothesis in explaining and predicting isomers, reference must be made to van't Hoff's *Chemistry in Space*, Clarendon Press, or to books on organic chemistry.

Other systems than the regular have hemihedral forms, but reference will only be made to the ortho-rhombic system. In studying this subject the student should have before him models 1, 2, 5, 6, 7, and 7A of Plate IV.

The general form of the prismatic system is that of figure 72,



Fig. 72.

or Plate IV., model 1. Suppress the faces $P_2, P_4, \bar{P}_1, \bar{P}_3$ of figure 72 ($z_2, z_4, \bar{z}_1, \bar{z}_3$ on model), and we have the sphenoid with the faces $P_1, P_3, \bar{P}_2, \bar{P}_4$ of figure 73A₁ ($z_1, z_3, \bar{z}_2, \bar{z}_4$ of model of Plate IV., 2). It is obvious that a second sphenoid with faces $P_2, P_4, \bar{P}_3, \bar{P}_1$ would be obtained by suppressing the faces $P_1, P_3, \bar{P}_2, \bar{P}_4$, as shown

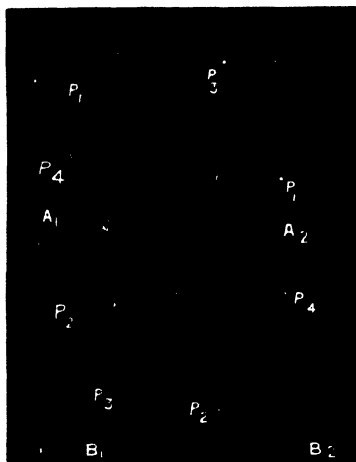


Fig. 73.

in figure 73B₁. These forms, as the student might judge, would be described as hemihedral with inclined faces, but we may now introduce a new term applied to these forms, viz.: *enantimorphous*.

With such forms we cannot by rotation about an axis bring the one form to coincide with the other;

but we can, by placing the one form in front of a looking-glass, obtain the other form by reflection, as the student may verify on trial with the models, Plate IV., 2 and 7A.

Make spherical projections of the two sphenoids referred to in the preceding paragraph, figure 73, A_2 and B_2 .

It would seem at first sight that rotating B_2 through 180° about the axis marked by a dotted line that we should have the figure A_2 , whereas the effect of the rotation will be to make the dots p_2 and p_4 in their new positions into circles occupying the position of the original circles of B_2 ,

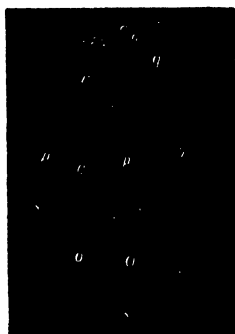


Fig. 74a.

and the circles will become dots occupying the position of the original dots. Again, if we try rotation round the vertical axis, we shall see that we can only reproduce the original figure. However, placing B_2 in front of a looking-glass, the reflection will have the appearance of A_2 . These sphenoids and generally asymmetric forms have the symbol $\alpha \{h \ k \ l\}$, the Greek letter α (Alpha) suggesting the word *asymmetric*.



Fig. 74A.

Another form may be derived from the general form of figure 72 by suppressing one plane of symmetry, the plane of the paper for example, when we have the upper pyramid only.

Forms of this kind are called *hemimorphic*.

Figure 74A is a drawing after Groth of a crystal of Smithsonite, and below it a rough spherical

projection of the same crystal. From the drawing and projections it will be seen that the forms $a = \{1\ 0\ 0\}$, $b = \{0\ 1\ 0\}$, $p = \{1\ 1\ 0\}$ are holohedral, while the forms $c = a\{0\ 0\ 1\}$, $o = a\{1\ 1\ 1\}$, $q = a\{0\ 1\ 1\}$, $q' = a\{3\ 1\ 0\}$, $r = a\{1\ 0\ 1\}$, $r' = a\{3\ 0\ 1\}$ are hemimorphic.

Some terms introduced by Professor Maskelyne in connection with mero-symmetry may not inappropriately be introduced here.

With any face of a crystal we may imagine a line at right angles to the face. This line is termed a *normal*.

In forms with parallel faces there is a face at each end of the normal. In these cases centro-symmetry is present, and the form is said to be *diplohedral*.

If the faces of the form have no opposite, that is, if centro-symmetry is absent, the form is said to be *haplohedral*. Each normal carrying but one face.

A *holo-systematic form* is one in which all normals due to the symmetry of the system are present, and each normal carries two faces, one at either end.

A *hemi-systematic form* is one in which only one-half the normals are extant.

These terms will be rendered clear by pointing out that:—

The forms, figures 60 (page 92) and 72 (page 97), are each holo-systematic and diplohedral.

The forms, figures 62 and 63 (page 92), are each hemi-systematic and diplohedral.

The forms, figures 68 and 69 (page 95), are each holo-systematic and haplohedral. Holo-systematic because all the normals of the full form (the octahedron) are present. Haplohedral because the normals carry only one face.

The forms, figures 73A₁ and 73A₂ (page 97), are also holo-systematic and haplohedral. They are asymmetric, as there is no plane of symmetry.

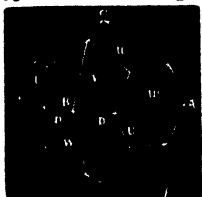
The forms c , o , q , q' , r , r' , of figure 74a (page 98), are holo-systematic and haplohedral; but there are two planes of symmetry present in these forms.

EXERCISES.

91. Make a spherical projection of the holohedral form $\{211\}$ of the regular system, and now, by striking out alternate groups of three poles in each octant, obtain one of the two hemihedral forms. Should these forms be written as $\pi\{211\}$ or $\kappa\{211\}$?

92. Make a spherical projection of the holohedral form $\{221\}$ of the regular system, and now, by striking out alternate groups of three faces in each octant, obtain the two hemihedral forms. Should these be written as $\pi\{221\}$ or $\kappa\{221\}$?

93. The annexed figure represents a form of the cubic system.



The face w has the symbol 321 , the face v the symbol 231 , and u the symbol 123 , A, B, C being the positions of 100 , 010 , and 001 poles respectively. Make a spherical projection of the form, and say from what holohedral form it is derived; further say whether it has inclined or parallel faces.

94. Make a spherical projection representing the following forms on a crystal of the prismatic system $\{100\}$, $\{010\}$, $\{001\}$, $\{111\}$. Also make a projection of the same crystal when each of the forms $\{100\}$, $\{010\}$, $\{001\}$ is hemimorphic.

95. Make a spherical projection of the crystal of exercise 94, but in which the form 111 is hemihedral, while the other forms are holohedral.

96. Turn over to pages 62 and 63, and say, in reference to the figures—

1. Are they all holohedral?
2. Are they all holo-systematic?
3. How many normals and how many faces has each figure?
4. Are these forms diplohedra or haplohedra?

APPENDIX.

MINERAL CLASSIFICATION

AND

DETERMINATION OF MINERALS

BY THEIR

EXTERNAL CHARACTERS,

AND BY THE USE OF

THE BLOWPIPE.

WHEN a mineral is placed in the hands of a student for identification, it may happen that it is at once recognised, just as we might recognise a Hindoo or a Chinese from peculiar traits we have observed in the few natives we have seen, or from pictures in books. A mineral species, however, will exist under such a variety of forms that, without wide experience, it becomes necessary to *try* the specimen in various ways, and see that its characters coincide with the recorded characters of the species.

An extremely valuable method by which to exercise the student in the determination of minerals is that adopted in Professor Groth's laboratory. A collection of minerals is arranged in glass cases, well exposed to view, and correctly labelled. A set of duplicates, but without arrangement, is placed in drawers to which the student has

access. A drawer is taken to the workroom, and the various specimens are determined in succession. To check his conclusions, the student at once goes to the labelled collection, when he will find out whether he is right or not.

In an attempt to become acquainted with minerals, it will, I think, be an advantage if the student in the first place confines himself to a limited number of the more important species. To assist him in this work he will find following these remarks

1. A list of one hundred minerals classified according to a natural system with the crystalline system and chemical formula of each mineral.
2. The same one hundred minerals arranged according to external characters, after the method of Dr. Albin Weisbach.
3. Instructions for the examination of minerals by the blowpipe.

In the general classification I have followed the arrangement adopted in the mineral gallery of the British Museum, as set out in Mr. Fletcher's valuable guide. See page 84.

In the tables for the determination of minerals by their external characters, the method of Dr. Albin Weisbach, as adopted in his "*Tabellen zur Bestimmung der Mineralien mittels äusseren Kennzeichen*" (Leipzig Arthur Felix), has been followed; but the tables are confined to the one hundred minerals of the classified list.

As regards blowpipe determinations, no tabular scheme is given, as I believe it will be better for the student to make himself thoroughly acquainted with the reactions of the elementary bodies by examination of known minerals, when he will be well qualified to determine the constituents of an unknown mineral. Where blowpipe characters of the mineral as a whole are characteristic, a hint or two is given with the tables of external character.

Method to be adopted in Examining an Unknown Mineral.

Take up the specimen supplied to you and decide clearly in your own mind

1. The lustre.
2. The colour.
3. The hardness.
4. The streak.

Then consult the following index to Weisbach's table, and turn to the required section, where you will find remaining characters supplied.

You must bear in mind that weathering, tarnish, and accidental circumstances, may give a false idea as to the lustre or other properties of a mineral, and it is impossible in the tables to provide for every condition in which a mineral species may present itself in nature.

Index to Weisbach's Table, page 113.

- | | | |
|-------------------------|-----------------------------|---------------------------|
| I. METALLIC STRE | { 1. Red, p. 113. | 4. Grey, p. 115. |
| | 2. Yellow, p. 113. | 5. Black, p. 117. |
| | 3. White, p. 115. | |
| II. SUB-METALLIC LUSTRE | { 1. Black Streak, p. 119. | 4. Yellow Streak, p. 123. |
| | 2. Brown Streak, p. 119. | 5. Green Streak, p. 125. |
| | 3. Red Streak, p. 123. | 6. Blue Streak, p. 125. |
| III. COLOUR-LESS STREAK | { 1. Very Soft, p. 127. | 4. Hard, p. 135. |
| | 2. Soft, p. 129. | 5. Very Hard, p. 137. |
| | 3. Medium Hardness, p. 133. | |

Having determined the mineral by external characters, you may now proceed to confirm the determination by blowpipe tests. Full instructions for this course are given commencing at page 150.

In reference to blowpipe work, I would particularly insist upon the student becoming thoroughly familiar with the tests as described at pages 140-150 before proceeding to examine an unknown mineral.

When the mineral has been determined reference should be made to the classified list of minerals, page 107, in order to learn its formula, and to see its position in the series.

The student will, if possible, check his results by reference to a labelled collection. See remarks, page 101.

The following index to minerals mentioned in this appendix will be useful.

Index to Names of Minerals mentioned in the Appendix.

NOTE.—C refers to mineral classification, page 107.

W refers to Weisbach's table, page 113.

B refers to blowpipe course, page 153.

Names with asterisks are synonyms generally to be found in the footnotes to Weisbach's table.

	C.	W.	B.		C.	W.	B.
Actinolite ...	109	134	...	Bleiglanz* ...	...	116	...
Adularia* ...	...	135	153, 154	Blende ...	107	118, 122	155
Agate ...	108	...	...	" ...	...	130	...
Alabaster* ...	...	126	...	Bog manganese ...	...	119	...
Albite ...	...	...	155	Boracite ...	111	138	153
Allophane ...	...	...	153	Borax ...	111	126	153, 155
Alum-stone* ...	...	130	153, 154	Bornite* ...	...	112	...
Alunite ...	111	130	153, 155	Bournonite ...	107	116, 117	153, 154
Almandine ...	...	136	...	" ...	...	...	155
Amazon-stone* ...	...	135	...	Brochantite ...	...	...	154
Amphibole ...	109	120, 122	...	Bronzite* ...	...	134	...
" ...	...	124	...	Brown	...	...	...
Analcime ...	110	134	155	haematite* ...	...	120	...
Andalusite ...	109	138	153	Brown spar* ...	...	132	...
Anglesite ...	111	128	154	Brucite ...	...	126	154, 155
Anhydrite ...	111	128	...	Calcite ...	108	128	153
Anorthite ...	110	136	...	Calamine ...	108	132	153, 155
Antimonite* ...	...	115	...	Carnallite ...	...	...	155
Apatite ...	111	132	153, 154	Carnelian ...	108	...	...
Apophyllite ...	109	132	153, 155	Cassiterite ...	108	120, 123	155
Aragonite ...	108	130	153	Celestine ...	111	128	155
Arsenic ...	107	114, 116	153	Cerussite ...	108	130	153, 154
Arsenical	...	...	...	Chabazite ...	...	...	155
pyrites* ...	...	114	...	Chalcedony ...	108	...	...
Asbestos ...	109	126	...	Chalcocryrite* ...	...	112	...
Atacamite ...	108	124	154, 155	Chalcotrichite* ...	...	122	...
Augite ...	109	125, 134	...	Chalybite ...	108	132	153, 154
Axinite ...	110	136	...	Chalkosin* ...	116	...	...
Azurite* ...	...	125	...	Chessylite ...	108	124	153, 154
Barytes ...	111	128	153	Chiastolite* ...	...	138	...
Baryto-calcite ...	...	...	153	Christophil* ...	...	...	...
Basaltic-	...	...	...	Chrysocolla ...	...	...	154
hornblende* ...	...	120	...	Chrysolite* ...	...	136	...
Beauxite ...	...	...	154	Chrysotile* ...	...	126, 131	...
Beryl ...	110	138	...	Cinnabar ...	107	122	154, 155
Biotite ...	...	127	...	Cobaltite ...	107	114	153, 155
Bismuthite ...	...	...	153	Cinnamon-stone	110	...	...
Bitter spar* ...	...	132	154	Copper ...	107	112	154

	C.	W.	B.		C.	W.	B.
Copper glance	107	116	154, 155	Jasper ...	108	...	...
Copper pyrites	107	112	154, 155	Jasper opal*	...	120	...
Corundum ...	108	138	153				
Cryolite ...	108	128	153, 154	Kaolin ...	...	...	153
" ...	...	...	155	Karstenite*	...	128	...
Cuprite ...	108	122	154	Kieselzinkerz*	...	132	...
				Kieserite ...	111	128	155
Dark-red				Kupfer lazure*	...	125	...
silver ore*	...	116	...	Kupfernickel*	...	112	153, 154
Desmin ...	...	130	...	Kupferkies*	...	112	...
Diamond ...	107	138	153				
Diopside ...	109	134	...	Labradorite ...	110	136	155
Dolomite ...	108	132	153, 154	Leucite ...	110	134	153, 155
				Lievrite ...	...	...	154
Eisenkiesel*	...	120	...	Light-red			
Emerald ...	...	138	...	silver ore*	...	...	...
Emery* ...	...	139	...	Limonite ...	108	120, 122	154, 155
Enstatite ...	109	134	...	Lölingite ...	...	...	154
Epidote ...	109	136	...				
Erubescite ...	107	112	154, 155	Magnesia mica	...	127	...
Essonite ...	110	...	...	Magnesite ...	108	132	153, 154
				Magnetic iron			
Fahlerz* ...	...	116	...	ore*	...	118	...
Feldspar ...	110	...	153	Magnetite ...	108	118	154
Fluor spar ...	108	130	153, 154	Magnetic pyrites	107	112	...
Franklinite ...	108	118	154, 155	Malachite ...	108	124	153, 154
				Manganite ...	108	116	...
Galena ...	107	116, 117	154, 155	Marcasite ...	107	112	154, 155
Galenite*	...	116	...	Meerschaum ...	109	126	...
Garnet ...	110	136	...	Melanterite ...	...	...	154
Gold ...	107	112	...	Menaccanite*	...	118	...
Göthite ...	108	120, 122	154, 155	Mercury ...	107	114	154
Graphite ..	107	116	153	Mesotype* ...	...	133	...
Grey copper ore*	...	116	153, 154	Microcline*	110	134	...
Grossularite*	110	136	...	Mimetite ...	111	130	154
Gypsum ...	111	126	153, 155	Mispickel ...	107	114, 116	153, 154
				" ...	...	...	155
Hæmatite ...	108	116, 118	154	Molybdenite ...	107	114	154, 155
" ...	...	122	...	Moonstone ...	...	...	...
Halite* ...	...	127	...	Mundic* ...	...	114	...
Heavy spar*	...	128	...	Muscovite ...	110	126	154
Hornblende ..	109	125, 134	...				
Hornstone ...	108	...	...	Natrolite ...	110	132	155
Hyacinth* ...	...	139	...	Niccolite*	...	112	...
				Nickeline ...	107	112	153, 154
Idocrase ...	109	136	...				
Ilmenite ...	108	118	...	Olivine ...	109	136	154
Iron pyrites ..	...	113	154, 155	Opal ...	108	120, 122	...
				" ...	...	132	...
Jargon* ...	...	139	...	Orpiment ...	107	122	153, 159

	C.	W.	B.		C.	W.	B.
Orthoclase ...	110	134	...	Smaltite* ...	107	114	153
Ouvarovite* ...	...	136	...	Smithsonite* ...	...	132	155
				Soapstone* ...	...	126	...
Pearl spar* ...	...	132	...	Sodalite ...	...	...	155
Peridot* ...	...	136	...	Spathose iron* ...	132	153, 154	...
Picotite ...	...	120	...	Specular iron	...	...	...
Platinum ...	107	114	...	ore* ...	117	...	...
Prehnite ...	...	...	155	Speiskobalt* ...	...	114	...
Proustite ...	107	122	153, 154	Spinelle ...	108	120, 125	154
" ...	...	...	155	Steatite* ...	...	126	...
Psilomelane ...	108	118, 119	154, 155	Stibnite ...	107	114, 116	153, 155
Pyrrargyrite ...	107	116, 117	153, 154	Stilbite ...	110	130	155
" ...	...	122	155	Strontianite ...	108	130	153, 155
Pyramidal				Sulphur ...	107	122	155
garnet ...	...	137	...	Sylvite ...	108	126	154
Pyrites ...	107	112	...				
Pyrolusite ...	108	114	154	Talc ...	109	126	153
Pyromorphite ...	111	128	154	" ...	127	...	...
Pyrope* ...	110	136	...	Tetrahedrite ...	107	116, 119	153, 154
Pyrrhotine* ...	...	112	...	" ...	...	...	155
Pyroxene ...	109	124	...	Tincal* ...	...	127	...
				Tin-white cobalt	...	114	...
Quartz ...	108	120, 123	...	Tin stone* ...	...	121	...
				Titaniferous			
Realgar ...	107	122	153, 155	iron ore* ...	...	118	...
Red iron ore* ...	...	117, 122	...	Topaz ...	109	138	154
Reddle* ...	...	117	...	Tourmaline ...	110	136	...
Redruthite* ...	...	116	...	Towanite* ...	...	112	...
Remolinite* ...	...	124	...	Tremolite ...	109	134	...
Rock salt* ...	...	127	...	Turquoise ...	111	134	...
Ruby ...	...	139	...				
Ruby copper* ...	...	122	...	Vesuvian* ...	...	137	...
Rutile ...	108	116, 117	...	Vivianite ...	111	124	154, 155
" ...	...	123	...				
				Wad ...	108	118	...
Salt ...	108	126	155	Wavellite ...	111	128	153, 154
Sapphire* ...	...	139	...	" ...	...	...	155
Schorl* ...	...	137	...	Websterite ...	...	...	153
Selenite* ...	...	126	...	Wheel ore* ...	...	116	...
Sepiolite ...	...	127	...	White iron			
Serpentine ...	109	130, 131	154, 155	pyrites* ...	...	113	...
Serpentine				Witherite ...	108	130	153
asbestos ...	...	126	...	Wolfram ...	110	120	154, 155
Siderite* ...	...	132	...				
Silver ...	107	114	154, 155	Zircon ...	108	138	...
Silver glance ...	...	...	154, 155				

One Hundred Minerals, with the crystalline system and chemical formula of each, classified according to the system adopted in the British Museum (Natural History).

NOTE.—The crystalline system is indicated by numbers following the names of the minerals. Thus “arsenic⁴,” “sulphur³,” imply that arsenic crystallizes in the hexagonal system, while sulphur crystallizes in the ortho-rhombic system. See index to numbers at foot of each page. The formulæ of the more complex minerals are from Groth’s *Tabellarische Übersicht der Mineralien*.

DIVISION I. NATIVE ELEMENTS.

Section 1. Metals.

Copper ⁶ Cu.	Silver ⁶ Ag.	Gold ⁶ Au.
Platinum ⁶ Pt.	Mercury ⁶ Hg.	Arsenic ⁴ As.

Section 2. Non-Metals.

Sulphur ³ S	Diamond ⁶ C	Graphite ⁴ C.
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DIVISION II. METALS WITH ARSENIC AND SULPHUR.

Section 1. Arsenides.

Nickeline ⁴ NiAs.	Smaltite ⁶ CoAs ₂ .
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Section 2. Sulphides.

(a) Blende⁶ ZnS. Galena⁶ PbS. Copper Glance³ Cu₂S.
Cinnabar⁴ HgS.

(b) Pyrites⁶ FeS₂. Marcasite³ FeS₂. Molybdenite⁴ MoS₂.
Realgar³ As₂S₂.

(c) Stibnite³ Sb₂S₃. Orpiment³ As₂S₃.

Section 3. Arseno-sulphides.

Cobaltite ⁶ CoSAs.	Mispickel ³ FeSAs.
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Section 4. Sulphur Salts.

Magnetic pyrites ⁴ Fe ₇ S ₈ .	Erubescite ⁶ FeCu ₅ S ₈ .
Copper pyrites ⁵ CuFeS ₂ .	Tetrahedrite ⁶ Cu ₈ Sb ₂ S ₇ .
Bournonite ³ CuPbSbS ₃ .	Pyrargyrite ⁴ Ag ₃ SbS ₃ .
Proustite ⁴ Ag ₃ AsS ₃ .	

1 = Anorthic.

2 = Mono-symmetric.

3 = Ortho-rhombic.

4 = Hexagonal.

5 = Tetragonal.

6 = Cubic.

DIVISION III. CHLORIDES AND FLUORIDES.

(1) Sylvite⁶ KCl. Salt⁶ NaCl. Fluor spar⁶ CaF₂.(2) Cryolite¹ 3NaF, AlF₃.

DIVISION IV. COMPOUNDS OF OXYGEN.

Section 1. Oxides.(1) *Oxychlorides.* Atacamite³ [Cu(HO)₂]₃ CuCl₂.*Monoxides.* Cuprite⁶ Cu₂O. Brucite⁶ Mg(HO)₂.*Epitrit-oxides.* Spinelle⁶ MgO, Al₂O₃.Franklinite⁶ (FeMnZn)O, Fe₂O₃.Magnetite⁶ FeO, Fe₂O₃.*Sesquioxides.* Corundum⁴ (Ruby, Sapphire) Al₂O₃.Ilmenite⁴ (FeTi)₂O₃.Hæmatite⁴ (Specular Iron Ore) Fe₂O₃.Göthite³ Fe₂O₃, H₂O.Manganite³ Mn₂O₃, H₂O.Limonite 2Fe₂O₃, 3H₂O.

Psilomelane and Wad are manganese oxides containing water, also a variety of metals, barium, potassium, &c.

Dioxides. Pyrolusite³ MnO₂. Cassiterite⁵ SnO₂.Zircon⁵ ZrSiO₄. Rutile⁵ TiO₂.Quartz⁴ SiO₂.

Varieties of Quartz are Jasper, Hornstone, Chalcedony, Agate, Carnelian, Opal.

*Section 2. Oxygen Salts.**a. Carbonates.*Aragonite³ CaCO₃. Witherite³ BaCO₃.Strontianite³ SrCO₃. Cerrusite³ PbCO₃.Calcite⁴ CaCO₃. Magnesite⁴ MgCO₃.Dolomite⁴ (CaMg)CO₃. Chalybite⁴ FeCO₃.Calamine⁴ ZnCO₃.Chessylite² (CuCO₃)₂, Cu(HO)₂.Malachite² CuCO₃, Cu(HO)₂.

1 = Anorthic.

3 = Ortho-rhombic.

5 = Tetragonal.

2 = Mono-symmetric.

4 = Hexagonal.

6 = Cubic.

*b. Silicates.**Monoxides.**a Orthosilicates.*Olivine³ $(\text{MgFe})_2\text{SiO}_4$.*β Metasilicates.*Enstatite³ MgSiO_3 .Pyroxene³ RSiO_3 (R = Ca, Mg, Fe, &c.)Amphibole³ RSiO_3 (R = Ca, Mg, Fe, &c.)

Pyroxene is a general term rather than special. The following are the names of two varieties :—Diopside $\text{CaMgSi}_2\text{O}_6$, Augite $(\text{MgFe})\text{CaSiSiO}_6$, $(\text{MgFe})(\text{AlFe})_2\text{SiO}_6$ (Groth).

Amphibole, like Pyroxene, is a general term ; varieties are Actinolite $(\text{MgFe})_3\text{CaSi}_4\text{O}_{12}$; Tremolite $\text{Mg}_3\text{CaSi}_4\text{O}_{12}$; Asbestos, Hornblende $(\text{MgFe})_2\text{CaMgSi}_2\text{Si}_2\text{O}_{12}$, $(\text{MgFe})_2(\text{AlFe})_4\text{Si}_2\text{O}_{12}$ (Groth).

*α and β hydrated.*Talc³ $\text{H}_2\text{Mg}_3\text{Si}_4\text{O}_{12}$.Meerschaum $\text{H}_4\text{Mg}_2\text{Si}_8\text{O}_{10}$.Serpentine $\text{H}_4(\text{MgFe})_3\text{Si}_2\text{O}_9$.Apophyllite⁵ $\text{H}_7\text{KCa}_4(\text{SiO}_3)_{14}\frac{1}{2}\text{H}_2\text{O}$ (Groth).*Sesquioxides.**Basic silicates.*Topaz³ $\begin{cases} \text{Al}(\text{AlF}_2)\text{SiO}_4 \\ \text{Al}(\text{AlO})\text{SiO}_4 \end{cases}$ Andalusite³ $\text{Al}(\text{AlO})\text{SiO}_4$.*Mixed oxides.**Basic silicates.*Idocrase⁵ $\text{H}_2\text{Ca}_8\text{Al}_4\text{Si}_7\text{O}_{29}$.Epidote² $\text{Ca}_2\text{Al}_3(\text{HO})(\text{SiO}_4)_3$.

1 = Anorthic.

3 = Ortho-rhombic.

5 = Tetragonal.

2 = Mono-symmetric.

4 = Hexagonal.

6 = Cubic.

Orthosilicates.

Garnet⁶ $\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$.

Garnet may be regarded as a general term. Common garnet occurring in schist is iron alumina garnet with small percentage of Mg, Mn, and Ca. Grossularite $\text{Ca}_3(\text{AlFe})_2(\text{SiO}_4)_3$. Essonite or Cinnamon Stone $(\text{CaFe})_3\text{Al}_2(\text{SiO}_4)_3$. Pyrope $(\text{MgFeCa})_3\text{Al}_2(\text{SiO}_4)_3$.

Acid orthosilicates.

Muscovite² $(\text{KNa})\text{H}_2\text{Al}_3(\text{SiO}_4)_3$.

Metasilicates.

Leucite⁵ $\text{KAl}(\text{SiO}_3)_2$.

Beryl⁴ $\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$.

Polysilicates.

Felspar $\text{R}'\text{R}'''\text{Si}_3\text{O}_8$.

Felspar is a general term. Orthoclase² $(\text{KNa})\text{AlSi}_3\text{O}_8$.

Microcline¹ $(\text{KNa})\text{AlSi}_3\text{O}_8$. Labradorite¹ $\begin{cases} \text{NaAlSi}_3\text{O}_8 \\ \text{CaAlAlSi}_3\text{O}_8 \end{cases}$

Anorthite¹ $\text{CaAl}_2\text{Si}_2\text{O}_8$.

*Zeolites with mixed oxides.**Basic metasilicates.*

Natrolite³ $\text{Na}_2\text{AlAlO}(\text{SiO}_3)_3, 2\text{H}_2\text{O}$.

Normal metasilicates.

Analcime⁶ $\text{NaAl}(\text{SiO}_3)_2, \text{H}_2\text{O}$.

Polysilicates.

Stilbite² $(\text{CaNa}_2\text{K}_2)\text{Al}_2\text{Si}_6\text{O}_{18}, 6\text{H}_2\text{O}$.

Silicates with Borates.

Tourmaline⁴ $(\text{R}'_2\text{R}'')\text{Al}(\text{BO})[(\text{AlOH})\text{SiO}_4]_2$.

Axinite¹ $\text{H}(\text{CaFe})_3\text{Al}_2\text{B}(\text{SiO}_4)_4$.

c. Molybdates and Tungstates.

Wolfram² $(\text{MnFe})\text{WO}_4$.

1 = Anorthic.

2 = Mono-symmetric.

3 = Ortho-rhombic.

4 = Hexagonal.

5 = Tetragonal.

6 = Cubic.

d. Sulphates.

α Anhydrous.

Anhydrite³ CaSO_4 . Celestine³ SrSO_4 .
Barytes³ BaSO_4 . Anglesite³ PbSO_4 .

β Hydrated.

Gypsum² $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$.
Kieserite² $\text{MgSO}_4 \cdot \text{H}_2\text{O}$.
Alunite⁴ $\text{K}(\text{AlO})_3(\text{SO}_4)_2 \cdot 3\text{H}_2\text{O}$.

e. Borates.

β Hydrated.

Borax² $\text{Na}_2\text{H}_2\text{B}_2\text{O}_8 \cdot 9\text{H}_2\text{O}$.

γ with Chlorine.

Boracite⁶ $\text{Mg}_7\text{Cl}_2\text{B}_{10}\text{O}_{30}$.

f. Nitrates.

g. Phosphates, Arsenates.

Vivianite² $\text{Fe}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$.
Wavellite³ $\text{Al}_6(\text{HO})_6(\text{PO}_4)_4 \cdot 9\text{H}_2\text{O}$.
Turquoise $\text{Al}_2(\text{HO})_8\text{PO}_4 \cdot \text{H}_2\text{O}$.
Apatite⁴ $\text{Ca}_5(\text{Cl or F})(\text{PO}_4)_3$.
Pyromorphite⁴ $\text{Pb}_5\text{Cl}(\text{PO}_4)_3$.
Mimetite⁴ $\text{Pb}_5\text{Cl}(\text{AsO}_4)_3$.

1 = Anorthic.

2 = Mono-symmetric.

3 = Ortho-rhombic.

4 = Hexagonal.

5 = Tetragonal.

6 = Cubic.

One Hundred Minerals arranged to assist
Dr. Albi

I.—MINERALS WITH

1. RED.

No.	NAME. HARDNESS.	COLOUR.	STREAK.	SPECIFIC GRAVITY.	TENACITY.
1	Copper H = 2½	Copper-red	Copper-red	8·5 – 8·9	Malleable
2*	Erubescite H = 3½	Between copper- red and brass-yellow	Black	4·9 – 5·1	Brittle
3*	Nickeline H = 5½	Light copper-red Bronze-yellow	Brownish- black	7·2 – 7·8	Brittle

2. YELLOW.

4	Gold H = 2½	Gold-yellow	Gold-yellow	14·5 – 19·1	Malleable
5*	Copper Pyrites H = 4	Brass-yellow	Greenish- black	4·2	Brittle
6*	Magnetic Pyrites H = 4½	Bronze-yellow	Black	3·8	Brittle
7*	Marcasite H = 6	Greenish-yellow Sometimes brown tarnish	Black	4·6	Brittle
8*	Pyrites H = 6	Greenish-yellow	Brown-black	4·9 – 5·1	Brittle

2*. *Synonymes.* Bornite, purple copper ore. A fresh fracture tarnishes in moist air to red, violet, blue. On charcoal magnetic residue.

3*. *Synonymes.* Kupfernickel, Niccolite. Seldom crystals. Grey or blackish tarnish on exposure.

5*. *Synonymes.* Chalcopyrite, towanite, kupferkies.

6*. *Synonyme.* Pyrrhotine. Feebly magnetic.

students in their determination by the method of
Leisbach.

METALLIC LUSTRE.

Purple, blue, grey from tarnish. See notes).

Index page 103.

SYSTEM. CLEAVAGE.	OCCURRENCE.	FRACTURE.	ASSOCIATED MINERALS.
Cubic	Massive Disseminated Plates, flakes Filiform	Hackly	Cuprite Malachite Copper pyrites Copper glance
Cubic 111 traces	Massive	Small conchoidal	Copper pyrites Malachite, &c.
* Hexagonal	Massive Disseminated	Conchoidal Uneven	Smaltite Arsenic Barytes, fluor, &c.

See also **Erubescite**, No. 2.)

Cubic	Disseminated Massive Plates, flakes		Pyrites, quartz Blende, galena Mispickel Stibnite
* Tetragonal 201 perfect	Massive Disseminated	Fine-grained	Malachite Bornite Galena, &c.
* Hexagonal 111 perfect 211 less per.	Massive Disseminated	Compact	Iron pyrites Copper pyrites Galena, blende, &c.
* Ortho-rhombic 110 distinct	Reniform Massive	Fibrous Fine-grained Compact	Pyrites, blende Galena Mispickel
* Cubic 100; 111 not distinct	Reniform Nodular Massive Disseminated	Conchoidal Compact Fibrous	Galena Blende Mispickel, &c

7*. *Synonymic.* White iron pyrites. Paler than pyrites. Emits smell of sulphur when pounded. Oxidises to sulphate more readily than pyrites. Occurs in chalk, clay, coal, &c.

8*. *Synonymic.* Iron pyrites. Smell of sulphur when pounded. Cubic faces often striated.

MINERALS WITH 3. WHITE.

No.	NAME. HARDNESS.	COLOUR.	STREAK.	SPECIFIC GRAVITY.	TENACITY.
9	Mercury	White		13.6	
10	Silver H = 2½	Silver-white	Silver-white	10 - 11	Malleable
11	Platinum H = 4½	Silver-white	Silver-white	18.9	Malleable
12*	Arsenic H = 4½	Tin-white to lead-grey	Greyish- black	5.7 - 5.8	Brittle
13*	Smaltite H = 5	Tin-white	Grey	6.3 - 6.6	Brittle
14	Cobaltite H = 5½	Reddish silver- white	Greyish- black	6.1 - 6.3	Brittle
15*	Mispickel H = 5½	Tin-white	Grey-black	7 - 7.3	Brittle

4. GREY.

16*	Molybdenite H = 1½	Reddish lead- grey	Bluish-grey	4.5 - 4.6	Sectile to flexible
17*	Pyrolusite H = 2	Between dark steel-grey and iron-black	Black	4.7 - 5	Sectile to brittle
18*	Stibnite H = 2½	Lead-grey	Grey-black	4.6 - 4.7	Sectile

12*. After exposure to air greyish black. Crystals seldom.

13*. *Synonymes.* Tin-white cobalt. Speiskobalt.

15*. *Synonymes.* Arsenical pyrites (mundic by Cornish miners).

METALLIC LUSTRE—CONTINUED.

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SYSTEM. CLEAVAGE.	OCCURRENCE.	FRACTURE.	ASSOCIATED MINERALS.
	In drops		Cinnabar
Cubic	Massive Disseminated Capillary, &c.		Argentite Pyrargyrite Proustite
Hexagonal	In loose grains In lumps	Angular grains	Chromite Gold Iridosmin
Hexagonal 111 perfect	Reniform Massive Disseminated	Curved columns Fine-grained	Proustite Galena Smaltine Fluor spar
Cubic a, c, d traces	Massive Disseminated Reniform	Compact Short fibres Fine-grained	Nicolite Bismuth Barytes Fluor spar
Cubic a perfect	Massive Small isolated crystals	Conchoidal	Copper pyrites Pyrites Skutteradite
Ortho-rhombic m tol. perfect	Massive Disseminated	Fine grains Silky	Blende Galena, &c.

also **Arsenic**, No. 12.)

Hexagonal c perfect	Disseminated Massive	Scaly	Wolfram Mispickel Cassiterite, &c.
Ortho-rhombic Pseudomorph 110, 100 010 distinct	Massive	Uneven Fibrous Granular	Psilomelane Barytes
Ortho-rhombic 100 perfect	Massive Crystals	Fibrous Granular	Kermes Pyrites, gold

16°. In thin leaves, very flexible. Colour and streak distinguish it from graphite No. 27.

17°. Soluble in hydrochloric acid with solution of chlorine.

18°. *Synonymic*. Antimonite. Thin leaves, flexible. Fuses in candle flame.

MINERALS WITH 4. GREY—Continued.

No.	NAME. HARDNESS.	COLOUR.	STREAK.	SPECIFIC GRAVITY.	TENACITY.
19*	Galena H = 2½	Reddish blue-grey	Dark-grey	7·4–7·6	Sectile
20*	Copper Glance H = 2½	Blackish lead-grey	Dark-grey	5·5–5·8	Sectile
21*	Bournonite H = 3	Between lead-grey and iron-black	Greyish-black	5·7–5·9	Brittle
22*	Pyrargyrite H = 3	Reddish lead-grey	Brown-red Cherry-red	5·8	Brittle
23*	Tetrahedrite H = 3½	Steel-grey to iron-black	Black Brownish-red	4·5–5·2	Brittle
24	Manganite H = 4½	Between dark steel-grey and iron-black	Dark red-dish-brown	4·2–4·3	Brittle
25*	Rutile H = 6½	Reddish lead-grey	Yellowish-grey or -brown	4·2–4·3	Brittle
26*	Hæmatite H = 6½	Between steel-grey and iron-black	Cherry-red Brown-red Red-brown	5–5·3	Brittle

B. BLACK. (See also **Mispickel**, No. 15 ; **Stibnite**, No. 18 ;

27*	Graphite H = 1	Iron-black	Black	1·8–2·1	Sectile Flexible
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19*. *Synonymes.* Galenite, Bleiglanz.

20*. *Synonymes.* Redruthite, chalkosin.

21*. *Synonymes.* Wheel ore.

22*. *Synonymes.* Dark red silver ore. Melts easily.

23*. *Synonymes.* Fahlerz. Grey copper ore. Some specimens have beautiful iridescence, due to limonite.

METALLIC LUSTRE—CONTINUED.

(See also **Arsenite**, No. 12.)

Index page 103.

No.	SYSTEM. CLEAVAGE.	OCCURRENCE.	FRACTURE.	ASSOCIATED MINERALS.
19*	Cubic 100 perfect	Massive, flaky Disseminated	Granular Compact, flaky	Blende, copper pyrites Tetrahedrite, &c.
20*	Ortho-rhombic 110 indistinct	Massive Disseminated Veins	Conchoidal	Copper pyrites Bornite Tetrahedrite, &c.
21*	Ortho-rhombic 100 indistinct	Massive Disseminated	Conchoidal	Tetrahedrite Copper pyrites Galena, &c.
22*	Hexagonal 100	Massive Disseminated	Conchoidal	Argentite Silver, &c.
23*	Cubic 100 imperfect	Massive Disseminated	Conchoidal Uneven	Copper pyrites Galena, &c.
24	Ortho-rhombic 100 very per. 110 perfect	Columnar and granular masses	Uneven	Barytes Calcite
25*	Tetragonal 100 pretty per. 110 pretty per.	Massive Disseminated	Conchoidal Uneven	Ilmenite Magnetic iron ore Hematite
26*	Hexagonal 111 distinct 100 distinct	Massive Reniform Disseminated	Conchoidal Uneven	

Galena, No. 19; **Bournonite**, No. 21; **Pyrargyrite**, No. 22; **Rutile**, No. 25.)

27*	Hexagonal 111 very per.	Massive Disseminated	Uneven	Gneiss Mica-schist
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25*. Unaltered in blowpipe flame. Microcosmic salt after addition of tin :—violet bead.

26*. *Synonymes*. Specular iron ore, red iron ore, reddle.

27*. Greasy feel, stains fingers. In thin leaves, flexible. Fused with nitre, deflagrates, the residue effervescing with acid.

MINERALS WITH

8.

No.	NAME. HARDNESS.	COLOUR.	STREAK.	SPECIFIC GRAVITY.	TENACITY.
28*	Magnetite H = 5½	Iron-black	Black Grey	4·9 - 5·2	Brittle
29*	Ilmenite H = 6	Iron-black	Black Reddish- brown	4·6 - 5·3	Brittle
30*	Franklinite H = 6½	Iron-black	Reddish- brown	5·1	Brittle
26	Hæmatite H = 6½ (Spec. iron ore)	Between iron- black and steel-grey	Cherry-red Brown-red	5 - 5·3	Brittle

II. MINERALS WITH SUB-METALLIC

1. BLACK OR DARK-GREY STREAK.

No.	NAME. HARDNESS.	LUSTRE.	COLOUR.	STREAK.	SPECIFIC GRAVITY.
31	Blende H = 4 (Var. Christophil)	Vitreous	Black	Brown- black	4
17a*	Psilomelane H = 6½	Metallic "Schimmernd"	Black	Black to brown	3·7 - 4·4

2. BROWN STREAK.

17b*	Wad H = 1	Dull	Dark brown	Dark brown	3·4 - 4
31	Blende H = 4	Adamantine Vitreous	Black Brown	Brown	3·9 - 4·2

28*. *Synonyme.* Magnetic iron ore. Attracted by a magnet.

29*. *Synonymes.* Menaccanite, titaniferous iron ore. More or less magnetic.

30*. Slightly magnetic.

METALLIC LUSTRE—CONTINUED.

Index page 103.

No.	SYSTEM. CLEAVAGE.	OCCURRENCE.	FRACTURE.	ASSOCIATED MINERALS.
28*	Cubic 100 distinct 111 distinct	Massive Disseminated	Conchoidal Uneven	Metamorphic rocks
29*	Hexagonal 111 perfect	Massive Disseminated	Conchoidal Uneven	Rutile Apatite, &c.
30*	Cubic 100 imperfect 111 imperfect	Massive Crystals Grains	Conchoidal	Zincite, calcite Willemite
26	Hexagonal 100 seldom	Massive Disseminated	Conchoidal Uneven	

LUSTRE AND COLOURED STREAK.

(All Opaque.)

No.	SYSTEM. CLEAVAGE.	OCCURRENCE.	FRACTURE.	ASSOCIATED MINERALS.
31	Cubic 110 very per.	Massive Disseminated Reniform	Granular Compact Fibrous	Magnetite Mispickel Galena, &c.
	Amorphous	Reniform Compact	Compact (Conchoidal)	Pyrolusite Limonite Barytes

(See also **Psilomelane**, No. 17a, and **Tetrahedrite**, No. 23.)

17b*	Amorphous	Reniform Compact	Earthy	Psilomelane Pyrolusite Limonite
31	Cubic 110 very per.	Compact Disseminated Reniform	Conchoidal Compact Fibrous	Mispickel Copper pyrites, &c.

17a*. Yields water in closed tube. Evolves chlorine readily when treated with hydrochloric acid.

17b*. *Synonymy.* Bog manganese.

MINERALS WITH SUB-METALLIC

2. BROWN STREAK—*Continued.*

NO.	NAME. HARDNESS.	LUSTRE.	COLOUR.	STREAK.	SPECIFIC GRAVITY.
32	Göthite H = $4\frac{1}{2}$	Adamantine Velvety Silky	Brown	Yellowish- brown	4.1 – 4.4
33*	Wolfram H = 5	Metallic Adamantine	Black Brown	Brown	7 – 7.5
34*	Limonite H = $5\frac{1}{2}$	Resinous to vitreous	Brown Blackish- brown	Yellowish- brown	3.4 – 4
37c.	Opal H = $5\frac{1}{2}$ (Var. Jasper opal)	Vitreous Resinous	Brown Black	Brown	1.9 – 2.3
35*	Amphibole H = $5\frac{1}{2}$ (Var. Basaltic hornblende)		Black	Yellowish- brown	2.9 – 3.4
36*	Cassiterite H = $6\frac{1}{2}$	Half metallic Resinous	Black Brown	Pale-brown	6.8 – 7
37*	Quartz H = 7 (Var. Eisenkiesel)		Brown	Pale-brown	2.5 – 2.8
38	Spinnelle H = 8 (Var. Picotite)	Vitreous Resinous	Black	Light-brown	4

33*. Sometimes slightly magnetic. Gives manganese reaction with a sodium carbonate bead. Microcosmic salt :—red bead becoming green on addition of tin.

34*. *Synonym.* Brown hæmatite.

LUSTRE AND COLOURED STREAK—CONTINUED.

Index page 103.

No.	SYSTEM. CLEAVAGE.	OCCURRENCE	FRACTURE.	ASSOCIATED MINERALS.
32	Ortho-rhombic 100 very per.	Compact Reniform	Imperfect Conchoidal	Limonite Hæmatite
33*	Mono-symmetric 100 perfect 010 imperfect	Compact Disseminated	Uneven	Cassiterite Quartz Quartz
34*		Reniform Compact Disseminated	Silky Compact Earthy	Pyrolusite Psilomelane Hæmatite
37c.	Amorphous	Compact	Compact Conchoidal	Limonite
35*	Mono-symmetric 110 very per.	Massive Disseminated		In basalt Phonolite
36*	Tetragonal 100 indistinct 110 indistinct			
37*	Hexagonal 100, 211, 122, very in- distinct	Massive	Conchoidal Compact	Limonite
38	Cubic	Disseminated	Compact	Serpentine Olivine, &c.

35*. Note prismatic cleavage yielding an angle of 124° . Tendency to columnar or fibrous character.

36*. *Synonymie.* Tin stone.

37*. *Synonymie.* Transparent crystals = rock crystal.

MINERALS WITH SUB-METALLIC

3. RED STREAK.

NO.	NAME. HARDNESS.	LUSTRE.	COLOUR.	STREAK.	SPECIFIC GRAVITY.
39	Cinnabar H = $2\frac{1}{2}$	Adamantine	Cochineal- red	Scarlet	8-8.2
40*	Proustite H = $2\frac{3}{4}$	Adamantine	Cochineal- red	Yellowish- red	5.5-5.6
22	Pyrargyrite H = 3	Adamantine Semi-metallic	Cochineal- red Blackish Lead-grey	Cherry-red Bluish-red	5.7-5.8
41*	Cuprite H = 4	Adamantine Semi-metallic	Cochineal- red Lead-grey	Brownish- red	5.9-6.1
26	Hæmatite H = $5\frac{1}{2}$ (Red iron ore)	Semi-metallic Earthy	Dark-red Steel-grey	Brownish- red	5.5-6.5

4. YELLOW STREAK.

Göthite, No. 32; Limonite, No. 34; Amphibole, No. 35; Opal;

42*	Orpiment H = 2	Resinous Pearly on 100	Citron- yellow	Citron- yellow	3.5
43*	Realgar	Resinous Adamantine	Aurora-red	Orange- yellow	3.6
44	Sulphur H = 2	Resinous Adamantine	Sulphur- yellow Brown-grey	Sulphur- yellow	
	Blende H = 4	Adamantine	Brown	Brown White	

40*. *Synonyme.* Light-red silver ore. Melts in candle flame.

41*. *Synonyme.* Ruby copper. Often black tarnish. Chalcotrichite is a variety occurring in acicular crystals (elongated cubes).

LUSTRE AND COLOURED STREAK—CONTINUED.

(See also **Quartz**, No. 37.)

Index page 103.

No.	SYSTEM. CLEAVAGE.	OCCURRENCE.	FRACTURE.	ASSOCIATED MINERALS.
39	Hexagonal 211 very per.	Massive Disseminated Flaky	Uneven	Quicksilver Copper Pyrites
40*	Hexagonal 100 distinct	Massive Disseminated	Compact	Argentite Stephanite, &c.
22	Hexagonal 100 perfect	Massive Disseminated	Conchoidal	Argentite Stephanite, &c.
41*	Cubic 111 distinct	Massive Disseminated Fibrous	Conchoidal Uneven	Copper Copper pyrites Malachite, &c.
26		Reniform Massive Powder	Compact Fibrous Earthy	Limonite Göthite Pyrolusite, &c.

Rutile, No. 25; **Cassiterite**, No. 36; **Quartz**, No. 37. See above.

42*	Ortho-rhombic 100 perfect	Massive Disseminated Reniform Plates		Realgar Stibnite Pyrites Clay, &c.
43*	Mono-symmetric 010 t. perfect 001 t. perfect	Massive Disseminated Flakes	Compact Earthy	Arsenic Stibnite Pyrites, &c.
44	Ortho-rhombic 111 imperfect 110 imperfect	Massive Disseminated Powder	Compact Earthy	Gypsum Celestine Clay, &c.
31	Cubic 110 very per.	Massive Disseminated	Conchoidal	Galena Copper pyrites Fluor, &c.

42*. Thin leaves, flexible, but not elastic. Burns.

43*. Burns.

MINERALS WITH SUB-METALLIC

5. GREEN STREAK.

Some varieties of **Amphibole**, No. 33.

NO.	NAME. HARDNESS.	LUSTRE.	COLOUR.	STREAK.	SPECIFIC GRAVITY.
45*	Malachite H = 3½	Vitreous Pearly Silky	Emerald- green	Verdigris- green	3·7 - 4
46*	Atacamite H = 3½	Vitreous to resinous	Emerald- green	Apple-green	3·7
47*	Pyroxene	Vitreous	Blackish- green Greenish- black	Grey-green	3·2 - 3·4

6. BLUE STREAK.

48	Vivianite H = 2½	Pearly Vitreous	Dark-green Greenish- black Indigo-blue	Indigo-blue	2·6 - 2·7
49*	Chessylite H = 3½	Vitreous	Blue	Smalt-blue	3·8

45*. Effervesces with hydrochloric acid. Soluble in ammonia to a blue fluid.

46*. *Synonymæ.* Remolinite. Soluble in ammonia to a blue solution. Characteristic flame colouration. See page 146.

LUSTRE AND COLOURED STREAK—CONTINUED.

and **Spinelle**, No. 36, give greenish streak.

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No.	SYSTEM. CLEAVAGE.	OCCURRENCE.	FRACTURE.	ASSOCIATED MINERALS.
45*	Mono-symmetric 001 very perfect 010 very perfect	Massive Reniform Disseminated	Conchoidal Fibrous Uneven	Copper minerals generally Limonite Hæmatite
46*	Ortho-rhombic 100 perfect 011 less perfect	Massive Disseminated Powder	Conchoidal	Limonite Hæmatite
47*	Mono-symmetric 110 tol. perfect	Massive Disseminated	Conchoidal Uneven	Amphibole Garnet Galena, &c.
48	Mono-symmetric 010 very perfect	Massive Disseminated Powder	Not observable	Limonite Pyrites Clay, &c.
49*	Mono-symmetric 021 perfect 100 less distinct	Massive Disseminated Powder	Conchoidal Compact Earthy	Malachite Limonite Copper pyrites, &c

47*. Refers mainly to Augite. See No. 33 as to distinction between augite and hornblende. See also page 134.

49*. *Synonyms.* Azurite, kupferlazur. Effervesces with hydrochloric acid. Soluble in ammonia to blue solution.

III.—MINERALS OF WHITE

1. VERY SOFT.

No.	NAME. HARDNESS.	LUSTRE.	COLOUR.	SPECIFIC GRAVITY.	TENACITY.
50*	Talc H = 1	Pearly	White Grey	2·6–2·8	Sectile Flexible
74a*	Chrysotile H = 2 (Serpentine Asbestos)	Silky	Green Brown		Sectile to brittle
51*	Gypsum H = 2	Vitreous Silky Pearly	White Grey Yellow Red-brown	2·3	Sectile Flexible
52*	Meerschaum H = 2	Earthy	Creamy White	1·2–1·6	Sectile
53*	Borax H = 2 (Tincal)	Resinous	White Grey	1·7	Brittle to sectile
54	Brucite	Pearly	White	2·3–2·4	Sectile
55*	Muscovite H = 2½	Pearly	Grey-white Light-brown Black	3	Sectile
56*	Salt H = 2½	Vitreous Resinous	White Grey, Red Blue (seldom)	2·2	Brittle to sectile
57	Sylvite H = 2½	Vitreous Resinous	White Grey	1·9–2	Brittle to mild

50*. Massive is soapstone or steatite. Lamina, flexible, but not elastic. Greasy feel.

74a*. Gives water in closed tube. When breathed upon has peculiar smell. Used extensively for asbestos board, &c. True asbestos is an altered hornblende.

51*. *Synonymie*. Crystallised = selenite. Massive = alabaster.

OR GREY STREAK.

(See Sulphur, No. 44 ; Vivianite, No. 48.)

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No.	SYSTEM. CLEAVAGE.	OCCURRENCE.	FRACTURE.	ASSOCIATED MINERALS.
50*	Ortho-rhombic 001 perfect	Massive	Flaky	Actinolite Dolomite Apatite, &c.
74a*		Veins	Fibrous	Serpentine
51*	Mono-symmetric 010 very perfect 111 imperfect	Massive Crystals Veins	Seldom observable	Clay Sulphur Rubbish of mines
52*	Amorphous	Massive Nodular		Chalcedony Opal chlorite
53*	Mono-symmetric 100 perfect 110 less perfect	Shores of lakes	Conchoidal	
54	Hexagonal 111 very perfect	Massive	Uneven Seldom obs.	Serpentine Limestone Chrome iron ore
55*	Mono-symmetric 001 perfect	Massive Disseminated	Sectile Elastic	Schists Gneiss, granite * Not augite nor labradorite
56*	Cubic 100 very perfect	Massive Disseminated Crystals	Conchoidal	Clay Gypsum Anhydrite
57	Cubic 100 perfect	Massive	Conchoidal	Carnallite Kainit

52*. *Synonyme.* Sepiolite. Adheres to the tongue.53*. *Synonyme.* Tincal. Puffs up or intumesces when heated, giving off water, and melting to a clear globule.

55*. Bistite or magnesia mica is black, dark-brown, or dark-green.

Compare Talc, No. 50*.

56*. *Synonymes.* Rock salt, halite. Characteristic taste.

MINERALS OF WHITE

2. SOFT.

COLOUR.

58*	Calcite H=3	Vitreous (111 pearly, dull)	All colours Gen. white	2·7	Brittle
59*	Anhydrite H=3	Vitreous Resinous Pearly	Grey White Bluish Reddish	2·8-3	Brittle
60	Celestine	Vitreous Resinous 001 pearly	White Bluish	3·8-4	Brittle
	Barytes H=3	Vitreous Adamantine 001 pearly Silky	White Red-brown Yellow Light-blue	4·3-4·6	Brittle
62*	Anglesite H=3	Adamantine Resinous	White	6·3	Brittle
63	Kieserite		White-grey Pale-yellow		Brittle
64*	Cryolite H=3	Vitreous Pearly	White Grey	3	Brittle
65*	Wavellite H=3	Vitreous Silky	All colours Yellow Green White	2·3-2·4	Brittle
66*	Pyromorphite H=3½	Resinous Adamantine	Green, white Brown Yellow	6·9-7·1	Brittle

58*. Effervesces with hydrochloric acid.

59*. *Synonyme.* Karstenite.61*. *Synonyme.* Heavy spar.

OR GREY STREAK—CONTINUED.

Index page 103.

No.	SYSTEM. CLEAVAGE.	OCCURRENCE.	FRACTURE.	ASSOCIATED MINERALS.
58*	Hexagonal 100 very perfect	Massive Disseminated	Conchoidal	
59*	Ortho-rhombic 100 and 001 very perfect 010 less perfect	Massive Veins	Conchoidal Imperfect	Clay Limestone Gypsum Rock salt
60	Ortho-rhombic 001 very perfect 110 less perfect	Veins Crystals	Conchoidal Fibrous Compact	Limestone Calcite, gypsum Sulphur
61*	Ortho-rhombic 001 perfect 110 perfect	Massive Crystals Fibrous masses Veins	Conchoidal Seldom obs.	Fluor, galena Pyrites Pyrolusite Limonite, &c.
62*	Ortho-rhombic 001 perfect 110 perfect	Massive	Compact Conchoidal	Cerussite Galena
63	Mono-symmetric	Massive	Conchoidal	Carnallite Kainit
64*	Anorthic Three directions near right angles to each other	Massive	Imp. conchoidal Uneven	Gneiss Chalybite Galena Copper pyrites Blende
65*	Ortho-rhombic 100 t. perfect 110 t. perfect	Reniform Hemispherical Radiating Crystals	Imp. conchoidal	Granite Slate Hematite Limonite, &c.
66*	Hexagonal 120 imperfect	Reniform Att. crystals Massive	Compact Imp. conchoidal	Cerussite Galena Barytes

62*. Melts in candle flame.

64*. Easily fusible.

65*. Often contains fluorine, and gives fluorine reaction.

66*. Contains chloride. After fusion crystallises on cooling.

MINERALS OF WHITE

2. SOFT—*Continued.*

NO.	NAME. HARDNESS.	LUSTRE.	COLOUR.	SPECIFIC GRAVITY.	TENACITY.
67*	Mimetite H = $3\frac{1}{2}$	Adamantine Resinous	Yellow Brown, grey White	7.2–7.3	Brittle
68	Cerussite H = $3\frac{1}{2}$	Adamantine Resinous Pearly, silky	White Grey Black Brown	6.4–6.6	Brittle
69	Stilbite H = 4 (Desmin)	Vitreous Silky Pearly	White Pale-yellow Pale-red, &c.	2.1–2.2	Brittle
70*	Alunite H = 4	Vitreous Pearly	White, grey Pale-yellow, &c.	1.7	Brittle
71	Strontianite H = 4	Vitreous Resinous	White, grey Pale-yellow Pale-green	3.6	Brittle
72	Witherite H = 4	Vitreous Resinous	White Grey Pale-yellow Greenish- white	4.2–4.4	Brittle
73*	Aragonite H = 4	Vitreous Resinous Silky	White, grey Red, green, &c.	2.9–3	Brittle
74*	Serpentine H = 3, 3.5	Resinous Feeble	Dark-green Red, &c.	2.5	Sectile
31	Blende H = 4	Adamantine	Yellow Red, green White	3.9–4.2	Brittle 110 very perfect
75*	Fluor Spar H = 4	Vitreous	All colours	3–3.2	Brittle

67*. Blowpipe reactions similar to those of 66.

70*. *Synonym.* Alum-stone.

73*. Phosphoresces when heated.

OR GREY STREAK—CONTINUED.

Index page 103.

No.	SYSTEM. CLEAVAGE.	OCCURRENCE.	FRACTURE.	ASSOCIATED MINERALS.
67*	Hexagonal 120 imperfect	Att. crystals In veins of galena, &c.	Imp. conchoidal	Galena Limonite Psilomelane
68	Ortho-rhombic 110 t. perfect 201 perfect	Massive Crystals	Conchoidal	Pyromorphite Galena Malachite, &c.
69	Ortho-rhombic 100 very perfect	Massive Characteristic groups	Uneven	Zeolites Calcite
70*	Hexagonal 111 imperfect	Massive Nodular	Uneven	Trachyte In gravel
71	Ortho-rhombic 110 tol. distinct 100, 201 imp.	Massive	Fibrous	Veins in older rocks
72	Ortho-rhombic 110 distinct	Massive Reniform	Uneven	Galena Alstonite Baryto-calcite
73*	Ortho-rhombic 100 distinct	Massive Reniform Acicular	Conchoidal Uneven	Calcite, gypsum Dolomite Limonite
74*		Massive	Conchoidal Flat, uneven	
31	Cubic	Massive Disseminated Roundish	Conchoidal Compact	Pyrites Pyroxene Galena, &c.
75*	Cubic. 111 very perfect	Massive Disseminated	Conchoidal	Barytes Galena Blende, &c.

74*. Serpentine has many varieties. 74 refers to British varieties. See

74a* Chrysotile, page 126.

75*. Some varieties phosphoresce when heated.

MINERALS OF WHITE

2. SOFT—*Continued.*

No.	NAME. HARDNESS.	LUSTRE.	COLOUR.	SPECIFIC GRAVITY.	TENACITY.
76*	Dolomite H=4	Vitreous Pearly (100)	White-grey Yellow, &c.	2·8–2·9	Brittle
77*	Chalybite H=4	Vitreous Pearly on 100 face	Yellowish- brown to red	3·5–4·5	Brittle

3. MEDIUM HARDNESS.

No.	NAME. HARDNESS.	LUSTRE.	COLOUR.	SPECIFIC GRAVITY.
78	Magnesite H=4½	Vitreous Massive Earthy	White Black Grey Pale-yellow	2·9–3
79*	Calamine H=4½	Vitreous to resinous	White-yellow Pale-green, &c.	4·3–4·4
80	Apophyllite H=6	Vitreous 001 pearly	White Pale-yellow Pale-red	2·3–2·4
81*	Apatite H=5	Vitreous Resinous	All colours	3·2
82*	Natrolite H=5	Vitreous Silky	White Pale-yellow Pale-red	2·2–2·3
37c	Opal H=5	Resinous Vitreous	In all colours	1·9–2·3

76*. *Synonymes.* Bitter spar, brown spar, pearl spar.

77*. *Synonymes.* Spathose iron. Siderite.

79*. Called Smithsonite by some authors. Smithsonite (Miller)=
Kieselzinkerz. Kieselzinkerz called calamine by some authors.
79* is a zinc carbonate. The other calamine is a zinc silicate.

OR GREY STREAK—CONTINUED.

Index page 103.

No.	SYSTEM. CLEAVAGE.	OCCURRENCE.	FRACTURE.	ASSOCIATED MINERALS.
76*	Hexagonal 100 perfect	Massive	Conchoidal Compact	Galena Blende Calcite, &c.
77*	Hexagonal 100 perfect	Massive Reniform	Conchoidal Compact	Galena Blende Copper pyrites, &c.

No.	SYSTEM. CLEAVAGE.	OCCURRENCE.	FRACTURE.	ASSOCIATED MINERALS.
78	Hexagonal 100 very perfect	Massive Reniform	Conchoidal Compact Earthy	Schists Serpentine
79*	Hexagonal 100 perfect	Reniform Botryoidal	Uneven Imp. conchoidal	Galena Blende
80	Tetragonal 001 very perfect 100 imperfect	Massive	Imp. conchoidal Uneven	Analcime Mesotype Calcite
81*	Hexagonal 111 imperfect 100 imperfect	Massive Reniform	Fibrous Compact Earthy Conchoidal	Cassiterite Wolfram, fluor Felspar, &c.
82*	Ortho-rhombic 110 perfect	Fibrous masses in basalt	Conchoidal Uneven	Chabasite Apophyllite Calcite
37c	Amorphous	Massive Disseminated Roundish, &c.	Compact Conchoidal	In crevices Many rocks

81*. Some varieties phosphoresce when heated; others when rubbed.

82*. *Synonymic.* Mesotype. Almost entirely soluble in oxalic acid.

MINERALS OF WHITE

4. HARD—

No.	NAME. HARDNESS.	LUSTRE.	COLOUR.	SPECIFIC GRAVITY.
83	Analcime H = 5½	Vitreous	White Pale-red	2·2–2·3
84*	Enstatite H = 5½	Vitreous Pearly on 100 face	Light-grey, green, brown, yellow, and red	3·2–3·6
85*	Leucite H = 6	Vitreous Resinous	White Grey	2·5
35a	Tremolite H = 6	Vitreous Silky	White Grey Greenish	2·9–3·4
35b*	Actinolite H = 6	Vitreous Silky	Green	3–3·2
35c	Hornblende H = 6	Vitreous	Black	2·9–3·4
47a	Diopside H = 6	Vitreous	Green White Yellow	3·2–3·4
47b	Augite H = 6	Vitreous	Grey-black Green-black	3·2–3·4
86	Turquoise H = 6	Vitreous Feeble	Azure blue Green	2·6–3
87*	Orthoclase H = 6	Vitreous 001 pearly	White Red Grey, &c.	2·5–2·6
87a*	Microcline H = 6	Vitreous 001 pearly	White Grey Green	2·5–4

84*. *Synonymy.* Bronzite.

85*. Apparently cubic in 24 faced trapezohedrons.

35b*. Breaks easily across prisms. Long bright green crystals called glassy actinolite. Fibrous kinds called asbestiform actinolite.

OR GREY STREAK—CONTINUED.

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NO.	SYSTEM. CLEAVAGE.	OCCURRENCE.	FRACTURE.	ASSOCIATED MINERALS.
83	Cubic 100 very imper.	Massive	Imp. conchoidal	Apophyllite Mesotype
84*	Ortho-rhombic 100 very perfect	Massive		Olivine Apatite Serpentine
85*	Tetragonal 011 very imper.	Disseminated	Conchoidal Uneven	Lava Sanidin Augite, &c.
35a	Mono-symmetric 110 perfect	Massive Fibrous	Sub-conchoidal	Dolomite
35b*	Mono-symmetric 110 perfect	Massive		Talc-schist Serpentine, &c.
35c	Mono-symmetric 110 perfect	Massive		Phonolite, &c. Syenite
47a	Mono-symmetric 110 tol. perfect	Massive	Conchoidal Uneven	Chlorite-schist Serpentine Garnet, &c.
47b	Mono-symmetric 110 tol. perfect	Massive Disseminated		Basalt Dolerite, &c. Not quartz
86	Amorphous	Disseminated Massive Reniform	Conchoidal Uneven	In pebbles
87*	Mono-symmetric 001 very perfect 010 perfect 110 traces	Massive Disseminated	Conchoidal Uneven	Augite seldom
87a*	Anorthic 001 perfect 010 clear	Massive Disseminated	Compact	Granite Syenite Hornblende, &c.

87*. Varieties are—(a) adularia, transparent, cleavable, pearly reflections (moonstone in part), (b) amazon stone, green.

87a*. Amazon stone, a mixture of orthoclase and microcline.

MINERALS OF WHITE

4. HARD—*Continued.*

No.	NAME. HARDNESS.	LUSTRE.	COLOUR.	SPECIFIC GRAVITY.
87 ^b *	Labradorite H = 6	Vitreous Resinous 001 pearly	White Grey brown	2.7–2.8
87 ^c	Anorthite H = 6	Vitreous 001 pearly	White Grey Red	2.7–2.8

5. VERY HARD.

88*	Epidote H = 6½	Vitreous Pearly	Green Yellow Brown, &c.	3–3½
89*	Olivine H = 7 (Peridot)	Vitreous Resinous	Green Yellow Brown	3.3–3.4
90*	Garnet H = 7	Vitreous Resinous	All colours except blue	3.1–4.3
91*	Tourmaline H = 7	Vitreous	All colours	3–3.3
92*	Axinite H = 7	Vitreous Part adamantine	Brown Grey	3.3
93*	Idocrase H = 7	Resinous Vitreous	Brown Yellow Green, &c.	3.4

87^b*. Play of colours produced by internal laminae and microscopic crystals of some other mineral (göthite or hæmatite).

88*. Prismatic forms often longitudinally striated. B.B. Fusible.

89*. As a precious stone called chrysolite or peridot. Sulphuric acid decomposes it with liberation of gelatinous silica.

90*. Grossularite = lime-alumina garnet. Pyrope = magnesia-alumina garnet. Almandine = iron-alumina garnet gives characteristic absorption spectrum. Ouvarovite = lime-chrome garnet. See page 110.

OR GREY STREAK—CONTINUED.

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NO.	SYSTEM. CLEAVAGE.	OCCURRENCE.	FRACTURE.	ASSOCIATED MINERALS.
87 ^b	Anorthic 001 very perfect 010 less perfect 110 imperfect	Massive Disseminated	Imp. conchoidal	Basalt Gabbro Not quartz
87 ^c	Anorthic 001 perfect 010 perfect	Massive Disseminated	Conchoidal	In grains in chalk
(See also 25, Rutile ; 36, Cassiterite ; 37, Quartz ; 38, Spinnelle.)				
88 ^a	Mono-symmetric 100 perfect 001 less perfect	Massive Disseminated	Uneven	Amphibole rocks Chlorite-schist, &c.
89 ^a	Ortho-rhombic 100 easy 010 traces	Massive Disseminated	Conchoidal	Basalt Gabbro Biotite Garnet, &c.
90 ^a	Cubic 110 difficult	Massive	Conchoidal	Pyrope in serpentine Essoinite, grossular in primitive rocks
91 ^a	Hexagonal 100 imperfect 111 imperfect	Massive Disseminated	Imper.conchoidal Uneven	Primitive rocks Almandine Beryl, topaz
	Anorthic Traces on several faces	Massive	Conchoidal	Hornblende-schist Blende Arsenical pyrites
93 ^a	Tetragonal 100, 110 not distinct	Massive	Imper.conchoidal	Primitive limestone Magnetite Pyrites, &c.

91^a. *Synonyme.* Schorl. Gives blowpipe reaction for boron.92^a. On looking through a crystal in direction of either optic axis a dark violet stripe is seen interrupted at the point occupied by the axis. Gives blowpipe reaction for boron. Fusible.93^a. *Synonyme.* Vesuvian, pyramidal garnet.

MINERALS OF WHITE
B. VERY HARD—Continued.

NO.	NAME. HARDNESS.	LUSTRE.	COLOUR.	SPECIFIC GRAVITY.
94	Boracite H = 7	Vitreous Adamantine	White Grey Greenish	2·8 - 3
95*	Andalusite H = 7	Vitreous Resinous	Red-grey Brown	3·1 - 3·2
96*	Beryl H = 7½	Vitreous	Green Blue White Yellow Pale-red	2·7
97*	Zircon H = 7½	Adamantine Resinous	All colours Often yellow Brown	4 - 4·7
98	Topaz H = 8	Vitreous Adamantine	Yellow White Pale-blue, &c.	3·4 - 3·6
99*	Corundum H = 9	Vitreous Resinous	Blue Red, green Grey, brown	4
100	Diamond H = 10	Adamantine (Type)	All colours	3·5 - 3·6

95*. Var. chialtolite. Impurities cause section to show a cross or other form.

96*. Var. emerald is green.

OR GREY STREAK—CONTINUED.

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	SYSTEM. CLEAVAGE.	OCCURRENCE.	FRACTURE.	ASSOCIATED MINERALS.
	Cubic 111 imperfect	Small crystals Massive	Conchoidal Uneven	Gypsum Anhydrite
95*	Ortho-rhombic 110 perfect to distinct	Massive	Sub-conchoidal Uneven	Schists Granite Almandine garnet, &c.
96*	Hexagonal 111, 011 Interrupted	Attached crystals	Conchoidal Uneven	Mica-schist Chlorite-schist Tourmaline Topaz, &c.
97*	Tetragonal 111, &c., not perfect	Disseminated	Compact	Eruptive rocks Granite, syenite Schists, &c.
98	Ortho-rhombic 001 very perfect	Disseminated Massive	Conchoidal	Granite
99*	Hexagonal 100 and 111	Massive Disseminated	Conchoidal Uneven	Granite Basalt
100	Cubic 111 very perfect	Massive Disseminated	Conchoidal	
	97*. Var. jargon, hyacinth.	Square prismatic forms.		Characteristic
		absorption spectrum (Miers).		
	99*. Var. pure transparent=sapphire and ruby.			
		Emery=granular corundum.		

The use of the Blowpipe in the Determination of Minerals.

Before commencing these lessons on the use of the blowpipe, the student will of course require to be provided with the necessary apparatus. The most convenient set of blowpipe apparatus I have seen is that published by John T. Letcher, Truro, known as the "Society of Arts Blowpipe Apparatus," price £1 1s.; but it is not at all necessary to have so complete a set. The student may very well commence with the following, which may be purchased from any of the dealers in chemical apparatus :—

1. A blowpipe.
2. A Bunsen burner. It is convenient to file the top of the burner so that it may slope somewhat, and should be supplied with the usual arrangement for closing the air holes. If gas is not available, a candle or oil lamp may be used.

A convenient burner is one represented in figure 75. The burner is mounted on an ordinary gas bracket swivel, which enables it to be inclined as may be required. At *b* is shown the position of the blowpipe jet for producing an oxidising flame. At *a* the position of the jet for producing a reducing flame.

3. Charcoal supports. Pieces of wood charcoal may be used, but these dirty the fingers, and are generally messy. A porcelain support and charcoal pastilles are much more convenient. Or, instead of porcelain, an aluminium support, as suggested by Lieut.-Colonel Ross, may be used. See "Manual of Blowpipe Analysis," by Lieut.-Colonel Ross (Trübner & Co.).

4. A small hammer.
5. Anvil.
6. A small magnet, or a magnetized penknife.
7. Pocket lens.
8. Platinum wire (see page 143).
9. Glass tubes, about 4 inches long, and one-quarter inch diameter, open at both ends (open tube).
10. Glass tubes, about 2 inches long, and one-eighth inch diameter, closed at one end (closed tube).
11. A silver plate or silver coin.
12. Solid reagents—borax, anhydrous carbonate of soda, potassium-dichromate, hydric-potassic sulphate, nitre (saltpetre), fluor spar*, copper oxide, magnesium ribbon, tinfoil, caustic potash, potassium cyanide, pyrolusite, Brazil wood paper.
13. Liquid reagents—hydrochloric acid, solution of cobalt nitrate, water.

The first thing the student should do is to acquire the knack of keeping up a continuous blast with the blowpipe. The principle of the method is to use the mouth as a reservoir of air having elastic sides. The supply of air to this reservoir is kept up by means of the lungs, while breathing is accomplished through the nose. Put the mouth-piece of the blowpipe in the mouth, close the nozzle with the finger, and then fill the mouth with air, distending the cheeks, so as to give the mouth as great a capacity as possible, and while keeping the cheeks distended, breathe through the nose. This presents no difficulty; but now let a little air escape from the nozzle of the blowpipe, and try to keep up the breathing through the nose as before. A little practice, and you will soon be able to keep up a blast through the nozzle of the blowpipe for a minute or two without inconvenience.

*Ammonium fluoride is a convenient blowpipe reagent. It is not necessary to mix hydric-potassic sulphate with this reagent when testing for boron.

Oxidising or outer flame. Reducing or inner flame. Take a piece of platinum wire, and at the end of it make a small loop, the diameter of a mustard seed, or a little larger. Make the loop hot, and dip it into some borax. The borax will adhere to the wire, and now heating the borax in the blowpipe flame you will obtain a *clear* glassy bead. When cool, moisten the bead with water, when you can take up on the bead any required powder. To study the two flames take up a minute quantity of manganese sulphate* (as much as will lie on the point of a needle will be sufficient). Heat the bead with the speck of powder in

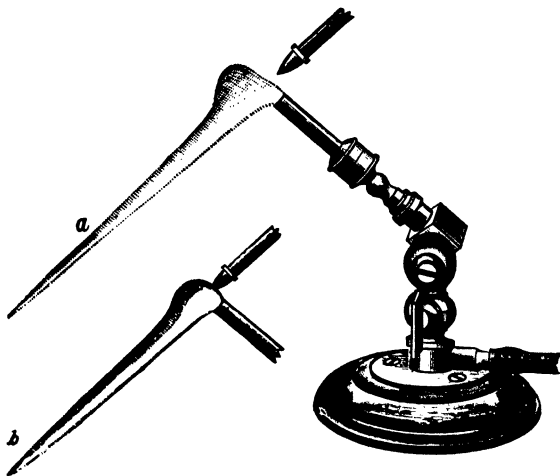


Fig. 75.

the oxidising or *outer flame*. You will obtain this flame by inserting the nozzle well into the flame, using a fairly strong blast (see figure 75*b*). Keep the bead near the end of the flame. The speck of powder will be gradually dissolved, and the bead will become of an amethyst colour throughout.

* A little manganese sulphate is placed with the box of specimens.

Now treat this bead in the reducing or *inner flame*. To obtain this, hold the nozzle of the blowpipe so as just to touch the flame, or slightly outside it, and blow gently, when a long tongue of white flame is obtained (see figure 75a). Hold the bead near the end, but well inside the flame, for a time, and then withdraw it. If you have been successful, the amethyst colour will have disappeared, and the bead will be colourless, or very much reduced in tone. Now place the bead in the outer flame, when the amethyst tint will return, and it may again be removed in the inner flame. Practice with a manganese bead in this manner until you have thoroughly mastered this important step in the use of the blowpipe.

Flame Colouration. Take a piece of *thin* platinum wire, moisten one end of it with *strong* hydrochloric acid, and hold it in the flame of the Bunsen burner. Should there be a yellow or other colour imparted to the flame, repeat the heating, and when the wire ceases to give a colour to the flame, which will be when the wire is quite clean, dip it again into the hydrochloric acid, and take up on the moistened wire a little of the powder to be examined. Try, for example, a little powdered heavy spar (barium sulphate). A little scraped from the specimen in box for example. At first the flame will probably be yellow, but afterwards a characteristic green colour will be given to the flame, sometimes rendered more distinct by treating the wire again with strong hydrochloric acid.

Instead of the Bunsen flame the outer blowpipe flame may be used. Flame colourations are obtained best with a high temperature flame and the metal in the form of chloride.

Since a high temperature is wanted, very thin platinum wire, as recommended by Bunsen, may be used with advantage. This wire being comparatively cheap, an end which has been used may be cut off, and a clean wire for the next experiment insured.

Metallic Beads. Many minerals when properly treated by the blowpipe flame on charcoal yield characteristic metallic beads. Place in a small cavity on charcoal, or on a charcoal pastille, a small piece of galena (a piece the size of a mustard seed will be sufficient); heat this in the blowpipe flame, when it will melt into a globule. This, however, is not a bead of lead, for if the globule is put on the anvil and struck with a hammer, you will find it to be quite brittle. Repeat the experiment, but put a little carbonate of soda with the galena, when after a time you will obtain a *metallic* bead, easily flattened under the hammer, and so soft that it will mark paper. It is, in fact, a bead of metallic lead.

In this particular case a bead of metal may be obtained before the carbonate of soda is added. As a rule, however, metallic beads are more readily obtained on the addition of carbonate of soda.

Incrustations. Many metals when heated on charcoal form an incrustation around the assay, that is, form a sublimate of the oxide of the metal. In the above experiment with galena a yellowish incrustation of litharge will most likely be met with.

Open and closed tubes. Place a fragment of gypsum in a closed tube, heat the tube gently over the lamp, when drops of water will be seen to collect on the sides of the tube.

Place a fragment of iron pyrites in a tube open at both ends (open tube); now incline the tube, and heat it where the fragment is placed. On smelling at the upper end of the tube the characteristic odour of burning sulphur will be perceived.

The student should try all of the following reactions, and become so familiar with them that if asked the blowpipe reactions for any of the elements he should be able to give them from a recollection of his experiments. Mere learning the reactions by rote from the written statements is worse than useless.

After familiarising himself with blowpipe work by making the foregoing experiments, the student may proceed to examine *known* minerals for the principal non-metallic and metallic radicals they contain.

In examining substances by the blowpipe there are four tests which may be called general, and which, in the case of an unknown mineral, should always be used. These are:—

Closed and open tube.	Charcoal.
Borax bead.	Flame colouration.

To the student unaccustomed to blowpipe work it is important to point out that, generally speaking, much better tests are obtained by using a minute quantity of the mineral to be tested rather than a larger quantity.

Below are arranged in alphabetical order the principal blowpipe tests for the common non-metallic and metallic radicals occurring in minerals. After the tests the names of minerals which may be used in making the tests are given.

Where a general test is omitted, it may be assumed that no reaction of consequence would be obtained if the test were applied.

A.—NON-METALLIC ELEMENTS.

Arsenic. (*a*) As native or as arsenide. In *closed tube*, black or grey metallic sublimate. In *open tube*, white fumes; characteristic crystals on cold part of tube. Heated *on charcoal*, white fumes; characteristic smell of garlic. *Flame colouration*: Livid blue.

Examples: Native arsenic, arsenical pyrites.

(*b*) As sulpharsenide. In *closed tube*, red sublimate first, afterwards as *a*. Remaining tests as *a*.

Example: Mispickel, cobaltine.

Boron. Borates. Mixed with ammonium fluoride or with excess of fluor spar and hydric-potassic sulphate, placed on a platinum wire, and held *just underneath* flame, the volatile boron fluoride comes off tinging flame characteristic green. Borax yields water in closed tube, and *intumescs* when heated on platinum wire, sinking afterwards to a clear glassy bead, even when cold. The bead dipped in glycerine and fired, the glycerine burns with a rich green flame.

Examples : Boracite, borax. (Borax gives reactions better than boracite.)

Carbon. Carbonates. As diamond no characteristic blowpipe test. Mixed with nitre in closed tube graphite deflagrates, and residue effervesces on addition of acid. Carbonates with borax bead give off bubbles of carbon dioxide. They effervesce with hydrochloric acid.

Examples : Diamond, graphite, calcite, magnesite, malachite.

Chlorine. Chlorides. Mixed with hydric-potassic sulphate and copper oxide in outer flame ; characteristic blue flame. Mixed with hydric-potassic sulphate and manganese peroxide ; characteristic smell of chlorine.

Examples : Rock salt, atacamite, cryolite.

Fluorine. Fluorides. Heated in *closed tube*, fluor spar often phosphorescent. Heated in *closed tube* with hydric-potassic sulphate fluorides give off hydrofluoric acid, which etches the tube. Glass rod moistened with water, and introduced into the tube, rod is covered with white crust of silica. Brazil wood paper is turned yellow by hydrofluoric acid.

Examples : Fluor spar, cryolite. Some varieties of apatite contain fluorine.

Phosphorus. Phosphates. Heated in *closed tube* with magnesium ribbon, magnesium phosphide formed.

On moistening contents of tube with water, phosphine evolved giving a characteristic garlic-like odour.

Examples : Apatite, pyromorphite.

Silica. (a) As rock crystal, sand, &c. Powdered and mixed with sodium carbonate, and heated on platinum wire, effervescence, and even when cold a clear glassy bead obtained, often coloured from metals in the impure silica.

Examples : Rock crystal, sand.

(b) As silicates. Heated with *microcosmic salt*, skeleton of silica floats in bead, the metals being taken up by the salt.

Example : Orthoclase.

Sulphur. (a) Native. Heated in *closed tube* melts to yellow liquid, afterwards goes dark, ultimately boils, and vapour may be lighted at mouth of tube, giving blue flame and characteristic choking smell of burning brimstone.

Example : Native sulphur.

(b) As sulphide. Heated in *closed tube*, yellow drops of sulphur form (with iron pyrites). Heated in closed tube with fragment of caustic potash, yellow mass obtained, which, when moistened on a silver coin, gives a dark stain. This test distinguishes a sulphide from a sulphate, since a sulphate when thus heated gives negative results.

Open tube, smell of burning brimstone. A piece of paper which has been dipped in potassium dichromate solution is turned green by fumes which come off.

Examples : Iron pyrites, copper pyrites, blende, galena.

(c) As sulphate. In *closed* and *open tube* no result. On *charcoal*, with carbonate of soda, a mass obtained, which, when moistened with water on a silver coin, produces a dark stain. *Closed tube*, with caustic potash, no result.

In testing for sulphur it is perhaps well to use a tallow or oil flame, as the sulphur in coal gas may give a false result.

Examples : Barytes, gypsum.

Water. In *closed tube*: Drops of water formed on cool part of tube if mineral contains combined water.

Examples: Gypsum, stilbite, limonite.

B.—METALS.

Aluminium. On *charcoal*, incandescent mass, which when moistened with cobalt nitrate, and again *strongly* heated, gives blue mass.

Examples: Websterite, alum.

Antimony. On *charcoal*, with sodium carbonate in outer flame, white smoke, and white deposit on charcoal. *Reducing flame*, small brittle metallic beads of antimony, which in outer flame give white fumes. *Flame colouration*, greenish blue.

Examples: Native antimony, stibnite.

Barium. *Flame colouration*, yellowish green.

Examples: Barytes, witherite.

Bismuth. On *charcoal*, with inner flame, pinkish white, slightly brittle metallic bead. In outer flame smokes a little, and gives brown incrustation. A mixture of potassium iodide and sulphur, mixed with bismuth or a bismuth compound, and then heated on charcoal, a rich red sublimate obtained.

Example: Metallic bismuth.

Calcium. Lime. *Flame colouration*, red.

Examples: Calcite, gypsum.

Cobalt. With *borax*, blue bead in both flames. Minerals containing cobalt have to be roasted, and afterwards the residue is heated with borax.

Example: Cobaltine.

Copper. On *charcoal*, with sodium carbonate, red metallic bead. With *borax* (outer flame): Green when hot, blue when cold. The blue bead becomes red in inner flame. The red colour is more easily obtained if a fragment of tin is added to the bead before reduction. *Flame colouration*, green.

Examples : Atacamite, cuprite, malachite (copper pyrites, flame colouration only).

Iron. *On charcoal* (inner flame), black markedly magnetic mass. *Borax* (outer flame), brownish yellow glass, which in inner flame is with difficulty changed to a delicate green. Tin may be added to assist reduction.

Examples : Hæmatite, limonite (Iron pyrites should be roasted before making the tests.)

Lead. *On charcoal*, with sodium carbonate, soft blue metallic bead, which will mark paper ; yellow incrustation. Assay mixed with potassium iodide and sulphur, a rich yellow sublimate obtained. Compare bismuth. *Flame colouration*, blue to violet.

Examples : Galena, cerussite.

Magnesium. *On charcoal*, incandescent pinkish mass obtained if the assay is moistened with cobalt nitrate, and strongly heated. The pink colour only seen well by daylight, or by light of burning magnesium ribbon.

Example : Magnesite.

Manganese. *With borax bead*, amethyst in outer, but colourless in inner flame. Iron and other metals may interfere with this test. If a bead of sodium carbonate, or of nitre, or of both, is first obtained on platinum wire, and the smallest quantity of a manganese mineral added, a green opaque bead is obtained on heating.

Examples : Pyrolusite, wolfram.

Mercury. *In closed tube* (as sulphide) black sublimate. With sodium carbonate, globules of mercury. In open tube, smell of burning brimstone, and grey deposit of metallic mercury.

Example : Cinnabar.

Molybdenum. See note *a*, page 155.

Nickel. The common nickel minerals do not give easy blowpipe reactions. See note *b*, page 155.

Example : Kupfernickel (nickeline).

Potassium. *Flame colouration*, violet. When sodium is present this test fails. If a flame, coloured from sodium and potassium salts, is viewed through a solution of indigo, in a test tube or hollow glass prism, the yellow is cut off and a red colour is seen. *Some* blue glass will also cut off the sodium flame, but the student must practise well on known salts before he can make much use of the test.

Examples : Sylvine, nitre.

Silver. Brilliant white malleable metallic bead.

Example : Pyrargyrite.

Sodium. *Flame colouration*, intense yellow.

Examples : Rock salt, glauberite, cryolite.

Strontium. *Flame colouration*, crimson. The student should compare the flame colouration of calcium with that of strontium. This may be done well by obtaining on one side of the Bunsen flame the one colour, and on the other side the other.

Example : Celestine.

Tin. *On charcoal*, with sodium carbonate, white soft metallic bead (difficult). With cyanide of potassium, metallic beads readily obtained.

Example : Cassiterite.

Zinc. *On charcoal*, after roasting, white incrustation, which, when moistened with cobalt nitrate and heated, becomes green.

Example : Blende.

On the Determination of Minerals by the Blowpipe.

When the student is familiar with the tests just described, he may proceed to recognise the constituents of unknown minerals by means of the blowpipe. To help in this work tables are published often in connection with books on mineralogy, which proceed on the dichotomic principle adopted in botanical schemes for the recognition of plants.

The use of such tables by a beginner is, however, to my mind to be deprecated, because, as in the corresponding tables for chemical analysis, a routine method is slavishly followed, and the student is not exercised in observing well himself what takes place, but is continually trying to make the phenomena fit in with a book description, instead of relying upon knowledge with which he should be familiar.

A convenient mode of practice is to get a friend to powder up *good** specimens of two or three dozen common minerals, and put them in pill boxes or tubes, preserving of course by means of numbers the possibility of identifying the specimens. These numbered specimens are then kept for exercise.

Taking now one of the specimens, apply in succession the four general tests:—

Closed and open tube.	Charcoal.
Borax bead.	Flame.

and some known reaction is almost sure to be obtained. Then calling to mind the characters of the elements as obtained by previous work (see page 145 *et seq.*), there will be little difficulty in recognising the constituents of the mineral.

The following list of common minerals, arranged under the elements contained in them, will be useful in connection with blowpipe work.

The student should bear in mind that there is not the same definite composition about many minerals that there is in salts and the powders generally given for chemical analysis. Thus, though cinnabar is essentially composed

* By good specimens I mean here specimens free from associated minerals. Some samples of crushed minerals supplied for blowpipe analysis by dealers will often contain so much gangue, that the blowpipe characters of the mineral itself are very difficult to obtain.

of mercury and sulphur, yet some specimens will give reactions for arsenic and other elements. Again, the constituents of minerals, in the silicates for example, cannot in many cases be detected by the blowpipe alone. These points should be kept in view when using the following list of minerals (page 153).

The student should always write down the particulars of his examination in a systematic manner. The following example will suggest a convenient method of proceeding:—

Example. The mineral under examination is of a brownish-white colour, and, under a magnifying glass, white prismatic crystals are visible.

Closed and open tubes gave same result, viz., a yellowish mass, but no recognisable gas came off.

Charcoal. A soft bead of metallic lead obtained.

Borax bead. No colour; some indication of effervescence.

Flame. Blue; indicative of lead.

On referring to the table, page 154, we find under lead the following minerals:—Galena, bournonite, cerussite, anglesite, pyromorphite, mimetite. Now galena and bournonite are excluded since in the open tube there was no indication of sulphur. On adding hydrochloric acid to the mineral effervescence takes place, indicating a carbonate. Hence the mineral is evidently cerussite.

NOTE.—If the student should be in doubt as to the chemical composition of any mineral given in the table of pages 153-155, he may turn to table, pages 107-110, where he will find the chemical formula given.

LIST OF COMMON MINERALS SUITABLE FOR
BLOWPIPE ANALYSIS, CLASSIFIED ACCORDING TO THE
ELEMENTS OR SUBSTANCES
INDICATED BY BLOWPIPE TESTS.

Arsenic. *Elements*, native arsenic ; *Arsenides*, nickeline (kupfernickel), smaltite ; *Arseno-sulphides*, cobaltite, mispickel ; *Sulpharsenites* and *Sulphantimonites*, tetrahedrite (grey copper ore), bournonite,* proustite,† pyrrargyrite* ; *Sulphides*, orpiment, realgar.

Aluminium. *Fluorides*, cryolite ; *Oxides*, corundum ; *Silicates*, aluminous silicates generally, some like adularia and the felspars, leucite, andalusite, allophe, apophyllite kaolin and the clays, give the alumina reaction, though not very readily ; *Sulphates*, alunite (alumstone websterite) ; *Phosphates*, wavellite.

Antimony. *Elements*, native antimony ; *Sulphantimonites* (see arsenic) ; *Sulphides*, stibnite.

Barium. *Carbonates*, witherite, barytocalcite ; *Sulphates*, barytes.

Bismuth. *Elements*, native bismuth ; *Sulphides*, bismuthite.

Boron. *Borates*, borax (tincal), boracite.

Calcium. *Fluorides*, fluor spar ; *Carbonates*, calcite, aragonite, dolomite, barytocalcite ; *Sulphates*, gypsum ; *Phosphates*, apatite.

Carbon. *Elements*, graphite, diamond ; *Carbonates*, aragonite, calamine, calcite, chessylite, cerussite, chalybite (spathose), dolomite, magnesite, malachite, strontianite, witherite.

Cobalt. *Arsenides*, smaltite ; *Arsenosulphides*, cobaltite.

* Sulphantimonite.

† Sulpharsenite.

Copper. *Elements*, native copper ; *Sulphides*, copper glance, copper pyrites, erubescite ; *Sulphantimonites*, tetrahedrite (grey copper ore), bournonite ; *Oxides*, *Oxychlorides*, cuprite, atacamite ; *Carbonates*, malachite, chessylite ; *Silicates*, chrysocolla ; *Sulphates*, brochantite.

Fluorine. *Fluorides*, fluor spar, cryolite ; *Silicates*, topaz ; *Phosphates*, apatite.

Iron. *Arsenides*, Lölingite FeAs_2 ; *Sulphides*, iron pyrites, marcasite ; *Arsenosulphides*, mispickel, erubescite, copper pyrites ; *Oxides*, magnetite, franklinite, hæmatite, göthite, limonite, beauxite ; *Carbonates*, chalybite (spathic iron ore) ; *Silicates*, iron is present in many silicates, lievrite is a silicate of iron and lime ; *Tungstates*, wolfram ; *Sulphates*, melanterite ; *Phosphates*, vivianite.

Lead. *Sulphides*, galena ; *Sulphantimonite*, bournonite ; *Carbonates*, cerussite ; *Sulphate*, anglesite ; *Phosphates* and *Arsenates*, pyromorphite, mimetite.

Magnesium. *Oxides*, brucite, spinelle ; *Carbonates*, magnesite, dolomite, bitter spar ; *Silicates*, olivine, serpentine, hornblendic minerals.

Manganese. *Oxides*, pyrolusite, psilomelane ; *Carbonates*, chalybite ; *Tungstates*, wolfram.

Mercury. *Elements*, native mercury ; *Sulphides*, cinnabar.

Molybdenum. *Sulphide*, molybdenite.

Nickel. *Arsenide*, nickeline (kupfernickel).

Phosphorus. *Phosphates*, apatite, pyromorphite, mimetite, wavellite, vivianite, native silver ; *Sulphides*, silver glance ; *Sulpharsenites*, proustite ; *Sulphantimonites*, pyrargyrite.

Potassium. *Chlorides*, sylvite ; *Silicates*, adularia, muscovite ; *Sulphates*, alumstone.

Silica. *Oxides*, rock crystal ; *Silicates*, all.

Silver. *Elements*, native silver; *Sulphides*, silver glance; *Sulpharsenite*, proustite; *Sulphantimonite*, pyrrargyrite.

Sodium. *Chlorides* and *Fluorides*, rock salt, cryolite; *Silicates*, albite, labradorite, leucite, natrolite, sodalite.

Strontium. *Carbonates*, strontianite; *Sulphates*, celestine.

Sulphur. *Elements*, native sulphur; *Sulphides*, blende, galena, copper glance, cinnabar, iron pyrites, marcasite, molybdenite, stibnite, orpiment, realgar; *Arseno-sulphide*, cobaltite, mispickel, erubescite, copper pyrites; *Sulpharsenites*, proustite; *Sulphantimonites*, tetrahedrite, bournonite, pyrrargyrite.

Tin. *Oxides*, cassiterite.

Tungsten. *Tungstates*, wolfram.

Water. *Chlorides* and *Fluorides*, carnallite; *Oxides*, atacamite, brucite, göthite, manganite, limonite, psilomelane; *Silicates*, prehnite, apophyllite, natrolite, analcime, chabazite, stilbite, serpentine; *Sulphates*, gypsum, kieserite, alunite; *Borates*, borax; *Phosphates*, vivianite, wavellite.

Zinc. *Sulphides*, blende; *Oxides*, franklinite; *Carbonates*, calamine; *Silicates*, smithsonite.

NOTES AND ADDITIONS.

a. Molybdenum gives green colour to flame, much like barium. On charcoal white coating becoming rich blue when touched for a moment with reducing flame.

b. To detect nickel by the blowpipe fuse with borax or charcoal, remove flux, heat residue with more borax, again remove flux. Repeat several times. Iron and cobalt may be removed by this method, and there is obtained at last a characteristic bead, violet when hot, and brown when cold.—(A. H. GREEN.)

ANSWERS TO THE EXERCISES.

11. Model B, Plate I.—

$$\begin{array}{ll} e_1 e_8 \text{ about } 50^\circ & m_1 m_2 = 111^\circ 42' \\ e_1 \bar{e}_7 \text{ ,, } 66^\circ & m_2 \bar{m}_1 = 68^\circ 18' \end{array} \left. \vphantom{\begin{array}{l} e_1 e_8 \\ e_1 \bar{e}_7 \end{array}} \right\} \begin{array}{l} \text{Exact measurement} \\ \text{on crystal.} \end{array}$$

12. 1. $m_1 m_2 \bar{m}_1 \bar{m}_2$. 2. $m_1 z_1 z_3 \bar{m}_1$.
 3. $m_2 z_2 z_4 \bar{m}_2$. 4. $z_1 z_2 \bar{z}_1 \bar{z}_2$.
 5. $z_2 z_3 \bar{z}_2 \bar{z}_3$. 6. $z_3 z_4 \bar{z}_3 \bar{z}_4$.
 7.

13. D has 12 edges; E has 14; F has 18. Note from this example that though the models D, E, and F are each and all models of the form known as the octahedron, yet the number of edges is different. The number and value of the angles is, however, the same in each.

14. If a quoin or solid angle is contained by three planes, as in a cube, and having of course three edges, no movement of the planes can introduce an additional edge. When, however, there are four planes forming the solid angle, then a movement of two of the non-adjacent faces will introduce a new edge. This is shown in model E, where two new edges are introduced by a movement of the planes $o_2 o_4$ and $\bar{o}_2 \bar{o}_4$; and again in model F, where, by movement of the planes $o_4 \bar{o}_3$ and $\bar{o}_1 o_3$, the maximum number of edges has been introduced.

15. $e_1, e_8, \bar{e}_{10}, \bar{e}_{19}, \bar{e}_1, \bar{e}_8, e_{10}, e_{12}; e_2, e_4, \bar{e}_3$, &c. $\bar{e}_1 \bar{e}_2$ are tautozonal with $e_1 e_8$. Other faces are heterozonal with these two.

21. (i.) Four. (ii.) Three. (iii.) Two. (iv.) From the crystallographic point of view the number of planes of symmetry in the rhomboid is the same as in the rhombus, for we may imagine the shorter lines of the rhomboid to move nearer together, or the longer ones to recede, without altering the angles of the figure, and produce a rhombus. (v.) One. (vi.) Infinite number.

22. (i.), (ii.), (iii.), all have nine planes of symmetry. (See remarks to 21.) (iv.) Infinite number. (v.) Nine.

23. Five. Three.

78.	$\infty P = 1 \quad 1 \quad 0$	$0 P = 0 \quad 0 \quad 1$
	$\infty \bar{P} \infty = 0 \quad 1 \quad 0$	$\infty P \infty = 1 \quad 0 \quad 0$
	$2 \bar{P} 3 = 6 \quad 2 \quad 3$	$\dot{P} \infty = 0 \quad 1 \quad 1$
	$\ddot{P} \infty = 1 \quad 0 \quad 1$	$3 \ddot{P} 2 = 6 \quad 3 \quad 2$

79. b and $\bar{b}$ are clinopinakoid planes. $m_1, m_2, \bar{m}_1, \bar{m}_2$ form the fundamental prism planes.

91. The map of the full form you will find to consist of three dots in each octant, with circles around to represent the three poles in the octant below. The dots in the positive octant are on the zones $a m_4$, $b m_4$, and $c m_4$ of figure 51. Striking out the groups of poles in alternate octants, there will be three dots in the positive octant, and three dots in the third octant, while there will be three circles indicating poles in the fifth octant, and three circles indicating poles in the seventh octant. (For position of octants see figure 4, Plate I.) It will be noted that the hemihedral form thus obtained indicates a tetrahedron with three small faces on each large face. It is, in fact, what is known as the triakis tetrahedron. It should of course be designated by $\kappa 2 1 1$.

92. $\kappa 2 2 1$.

93. It is derived from the form $1 2 3$ by leaving out alternate faces. It has parallel faces, and is represented as $\pi \{1 2 3\}$.

96. All holohedral. All holo-systematic. 41 has 24 normals 42 has 12, &c. The forms are all diplohedra.

Notes on the Specimens accompanying this Book.

THE crystals and apparatus are not labelled, but the student will have little difficulty in recognising the specimens, since they are placed in the box in the order indicated by the label on the lid. The piece of mica is laid on the top of the cotton wool covering, and is seen directly the box is opened. The rod for Senarmont's experiment is at the bottom of the narrow partition. The fluor spar, for phosphorescence, is at the bottom of the larger glass tube. This tube may be used as described at page 82. The paraffin wax, for Senarmont's experiment, is wrapped in tinfoil, and inserted in a small tube. At the bottom of the small tube is the manganese sulphate, spoken of at page 142.

It is obvious that the sets cannot be uniform. I have tried, however, by selection from superior and average specimens, to make each box of about equal value. Some of the crystals have been obtained with difficulty, and should there be much demand for the sets, it is possible a substitution may have to be made in one or two cases.

I should wish to express my obligations to Messrs. Henry Wiggin & Co., and their Chemist, Mr. G. H. Boeddicker, for some of the artificial crystals, which will be found particularly valuable to the student.

Copper sulphate.—The faces of the best specimens can be recognised by a comparison with the model H of Plate III., by applying the cardboard goniometer, or comparing with the model the angles made by the edges of the crystals.

It is seldom that the cleavage can be seen. I have only noticed it on one specimen. When cleavage can be found it is valuable in determining the face. Thus with copper sulphate, the face *m* of the model is the one that is parallel to an imperfect cleavage plane.

Barytes.—The specimens are of two or three kinds, as already mentioned (page 14). In some the pearly character of the 001 face is very noticeable, and the cleavage lines parallel to the $\{110\}$ faces are well seen. The long prisms with dull faces, corresponding to model 8 of Plate IV., show lines indicating cleavage parallel to the 100 face as well as to the 110 faces. Some of the crystals have the plane $c=001$ much developed, and would be called "tabular."

The student will find the barytes crystal of great value as illustrating the use of cleavage in recognizing planes. However irregular the crystal may be, the cleavage planes parallel to the 110 planes are sure to be indicated; and this indication, even without the characteristic pearly plane, is sufficient to put the crystal "in position."

Calcite.—Some have the appearance of figure 56; others are in long prisms, terminated by many planes; the extreme end of the prism showing a six-sided pyramid. The terminal planes when like those of figure 56 are commonly striated, the direction of the striations being parallel to the intersections of these planes with the rhombohedron. These striated faces are apparently the 011 planes of Miller. Cleavage lines indicating the fundamental rhombohedron are to be met with in all the specimens I have looked at. The cleaved specimen in some cases is sufficiently transparent to show double refraction. To observe this a pinhole is made in a card, and the cleaved specimen placed against this and held up to the light, when two pinholes will be seen. The other specimens are sufficiently referred to in the body of the work.

NOTE.—The specimens and apparatus are to be obtained only from Messrs. White & Pike Limited, Moor Street Printing Works, Birmingham, by filling up the accompanying form, and enclosing postal order for 3s. 6d.

To
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